DOCUMENT RESUME

ED 325 337 SE 051 673

AUTHOR	Neal, Homer A., Ed.; Wilson, Jack M., Ed.
TITLE	The Future of U.S. Doctoral Programs in Physics (May 22-23, 1989). Topical Conference Series.
INSTITUTION	American Association of Physics Teachers, College Park, MD.
REPORT NO	ISBN-0-917853-39-3
PUB DATE	90
NOTE	132p.
AVAILABLE FROM	American Institute of Physics Teachers, 5112 Berwyn Road, College Park, MD 20740 ($12.00 prepaid).
PUB TYPE	Collected Works - Conference Proceedings (021)
EDRS PRICE	MF01/PC06 Plus Postage.
DESCRIPTORS	*College Science; Conferences; *Demand Occupations; Doctoral Degrees; *Educational Trends; *Females; Higher Education; *Minority Groups; *Physics; Science Education

ABSTRACT

The 1990's represent an unusual period in physics. Some areas are in a state of unusual excitement, while there are divisions growing within the discipline over priorities. Another problem facing the field at this time is that few U.S. nationals are going into careers related to physics. In addition, the percentage of females and minorities pursuing studies related to physics continues to be extremely small. This conference was organized to focus on these concerns. It was designed to share information on trends in physics and physics education and to facilitate discussion within the discipline. This document contains 23 papers presented at the 1989 conference, the text of four summary resolutions, correspondence, and lists of the steering committee and conference participants. (CW)

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The Future of U.S. Doctoral Programs in Physics

Edited by:
Homer A. Neal
&
Jack M. Wilson

TOPICAL CONFERENCE SERIES

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The Future of U.S. Doctoral Programs in Physics

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May 22–23, 1989

American Association of Physics Teachers

The Future of U.S. Doctoral Programs in Physics
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Published by:
American Association of Physics Teachers
5112 Berwyn Road
College Park, MD 20740-4100

Cover: Rebecca Heller Rados

ISBN #: 0-917853-39-3

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The Future of U.S. Doctoral Programs in Physics

Introductory Remarks by Homer A. Neal

Chair of the Steering Committee

On behalf of the Steering Committee, I would like to welcome you to today's conference on The Future of U.S. Doctoral Programs in Physics. As noted in the program, the Steering Committee members include Stephen Baker, Charles Bean, Mildred Dresselhaus, Douglas Fitchen, Helmut Fritzsche, Eugene Loh, Richard Patty, James Stevenson, Robert Swenson, Brian Schwartz and Jack Wilson. The idea for the conference originated with Robert Resnick, during his tenure as president of AAPT. We are pleased that he was able to participate in the conference and share his perspectives.

This is an unusual period in physics. Several of our subfields are in states of extraordinary excitement. One only has to mention phrases such as superconductivity, stopping of atoms, the SSC, positron microscope, the Siberian snake, b factories, CEBAF, RHIC, Tevatron upgrade, KAON, laser interferometer gravity wave detector, supernovae 1987a, and so on, to be reminded of just how dynamic our field is today. At the same time, we note that divisions are growing within our community over priorities, and that more and more discussions are focusing on just what are the best modalities at the national level for supporting research. This is one of the reasons why a meeting of the nation's physics department chairs seems very appropriate. Another reason is that in addition to facing issues of national policy and internal harmony among subfields, there are numerous other detailed matters that we as chairs must face – matters which collectively will have a major impact on the future of our field.

Why are there so few U.S. nationals going into graduate study in physics? Why is there the perception among many of our undergraduates that a career in physics is not attractive? Why are there so few women and minorities pursuing graduate studies in physics? Does the graduate physics curriculum need revision and, if so, in what ways? Are we properly providing for the needs of our foreign students? Is the GRE exam as useful as it might be to our departments in selecting outstanding students – if not, why not?

The percentage of Ph.D.s awarded to females is small and almost constant (only 1 Ph.D. in 10 goes to a female); why is this so? Over half of our departments have 0 female faculty; over 87 percent have 1 or fewer female faculty. The average student now requires 6.4 years to complete his or her degree; why so long? Between 1972 and 1987, the fraction of graduate students who are foreign almost doubled; are we properly providing for these students? These are just a small number of the evolving issues affecting our field.

The conference is organized with several points in mind. First, we want to hear directly from the federal agencies regarding their plans for the support of science in the years ahead, both to inform us and to give us an opportunity to influence these plans. We are pleased to note that we have representatives from NSF, DOE and DOD with us in this context.

Second, we want to use the conference as a vehicle for sharing the latest data on graduate education. In fact, as a result of the efforts of the Steering Committee – especially Bob Swenson and Douglas Fitchen, the AIP has prepared a comprehensive analysis on the status of graduate education in physics. This report will be discussed in some detail by Beverly Porter. Several other presentations also pertain to trends in graduate physics education.

Third, taking a hint from our friends in the legal profession, we thought that it would be useful to share case studies of successful graduate programs. In this connection, we are pleased that the chairs at Stanford and MIT have consented to talk on activities at their institutions.

Finally, we wanted to provide a forum for discussing the myriad of issues that confront all of us on a daily basis. Much of the discussion on these topics will arise in Panel Discussion 1. That panel will be chaired by Douglas Fitchen from Cornell who, in addition to overseeing the orderly flow of matters, will see that several of the key topics will be raised for discussion.

I would like to urge each of you to think of possible conference follow-up items. One possibility would be the request for a meeting with the President's Science Advisor to review a list of recommendations developed as a result of this conference. Similar meetings or correspondence could be shared with the heads of appropriate agencies and the AAPT and APS. Other initiatives might be considered. If you have such suggestions, please contact a Steering Committee member.

I hope you will find the conference stimulating and productive.

Opening Remarks

Gerald F. Wheeler

1989 President, American Association of Physics Teachers

The American Association of Physics Teachers (AAPT) takes great pride in cosponsoring this important Topical Conference on Issues in Graduate Physics Education and Research. This is the fifth such conference on physics education and the first on the subject of our graduate-education programs in physics. It is especially heartening to see that the majority of the department chairs from the doctoral-granting institutions in the country are here.

The AAPT has a diverse membership, sharing the common goal of improving physics teaching. This involves the teaching of physics within the pre-secondary classrooms, in high schools, in two-year colleges, in four-year colleges, as well as the many special types of teaching that take place during the education of a graduate student of physics. This conference focuses on that last part of the spectrum – improving the state of graduate education in physics.

Over the years of cosponsoring these events, the American Physical Society (APS) and AAPT leadership have always begun the conferences by making the point that there is a common interest of the two groups for the topic being discussed. Usually, the presentation makes the connection between the health of the research community being dependent on the early "pipeline" supply of high school and undergraduate physics students. For this conference, the connection is so obvious that little needs to be said. There are many direct connections between the issues of graduate education in physics and the health of the physics community.

It would be pretentious of me to suggest actions, or outcomes, for this conference; you people are the experts. The point of this gathering is, rather, to create a critical mass of experts and let the actions emerge naturally. I would like to suggest, however, that many issues that might be identified in a gathering of physics department chairs could probably start with the phrase, "We need more... from...." While these statements about external factors characterize important issues, I hope that we use this gathering to also reflect on *our* role in the issues. In addition to needing more resources, we need to challenge ourselves to examine issues over which we have direct control. Issues within this category range from the types of experiences we offer to our graduate students to the kinds of students we are identifying, actively attracting, and successfully retaining in our programs.

If this conference stays true to the tradition of the previous conferences, there will be opportunities here to raise consciousness, to enlist new participants in important causes, to generate new solutions to old problems, and to accelerate needed changes. The ideas and resolutions that come out of these conferences can lead to action.

So, as President of one of the sponsoring organizations, I welcome you to the fifth Topical Conference of department chairs. I hope that we can make progress on issues during this conference that will improve the education of physics graduate students in our country.

Some Issues in Graduate Physics Education

Robert Resnick

From past conferences and my extensive travels during the years of my being an officer in the AAPT, it became clear to me that there was a need to focus on problems in graduate education in physics. That led to my proposing that the AAPT organize this topical conference on issues in graduate physics education and research. Several of the issues are at the interface of undergraduate and graduate education, and although for various reasons the chairs of departments at non–Ph.D. granting institutions are not with us, those issues can and should be addressed here. After all, the Ph.D. granting institutions all have undergraduate programs also and supply graduate students to one another. Many other issues are strictly at the graduate or post–graduate level, of course.

I think the simplest thing I can do is to read from the notes I made in proposing such a conference over 16 months ago and suggest that, amongst other matters, you consider here the issues I cited then.

A. First there are the interface issues:

1. The graduate record exam: who uses it? does it properly represent undergraduate physics major programs, and if not which should be changed? does it properly represent the preparation graduate physics programs desire? Should it be ignored and, if not, how can we influence it? More generally how can we get an impedance match between the graduate and undergraduate programs?
2. The departmental qualifying exams for incoming graduate students: what form does it take – oral or written, for example, and what is its scope and timing? how is it used for course placement or degree qualification? how can departments exchange information and match standards on this?
3. Graduate teaching assistants: what training is or should be given for the teaching of introductory labs and recitation sections? the language problems of foreign – born T.A.'s and programs to solve them; the benefits and drawbacks to the use of graduate teaching assistants and alternative uses of their services.
4. Undergraduate research participation programs: benefits in attracting physics majors; the pros and cons for using undergraduates in research programs; example of established programs and successful techniques used.

B. Then there are the strictly graduate issues:

5. Revision of the graduate curriculum: survey recent developments and exchange views.

6. Computational physics: is it becoming an established part of the graduate program? seek examples of established or successful programs for guidance of and consideration by others.

7. The need for American – born graduate physics students: the extent of the need, if it in fact exists; the pros and cons of dependence on foreign – born students; how to meet the need – if it exists – as e.g. by graduate fellowship programs and the like.

8. Meeting the need for more women and minority physics graduate students: how to use those already in physics as role models; questions of equity; increasing the supply.

9. The length of physics Ph.D. programs: does it need to be shortened?; if so, why, and how to do it?

10. Thesis assignment to individuals in large group research areas – problems and solutions. At one school I heard facetiously of the requirement that the student had to be present in the accelerator lab the night his or her thesis was run.

11. The responsibility of graduate programs for the preparation of physics teachers at the high school, junior college or higher levels: survey existing programs and the techniques used; what can or should be done?

12. The supply of and demand for Ph.D. physicists: as a function of time and projected ahead, by subfields, by type of employer, etc.; and response to the needs – including entrance into and exits from the pipeline.

C. Finally, a very general issue:

13. The increasing specialization of physics research areas and of the teaching by research physicists: implications for the coherence and unity of physics itself, of physics departments, and physics societies; the implications for undergraduate teaching programs and particularly for the introductory physics course.

This issue, while related to graduate and undergraduate education, goes well beyond those areas to post–doctoral and faculty attitudes and activities, of course. It looms as a fundamental issue that we seem not yet ready to face.

Well, that's it. Some of these issues will be addressed explicitly or implicitly in the prepared invited talks, and some not at all. Of course they are interconnected. For example, a discussion of graduate fellowships impinges on the graduate record exam, graduate teaching assistants, the need for American–born graduate physics students, getting more minority physics graduate students, the length of Ph.D. programs and the supply of Ph.D. physicists. But I'd like you to be conscious of these separate issues, as well as their interconnections, and speak to them at the appropriate time so that we can all benefit from the exchange of ideas and views.

STATISTICAL TRENDS IN GRADUATE EDUCATION

Beverly Fearn Porter
American Institute of Physics

INTRODUCTION

For the past several years I have been speaking about "the coming decade of the 1990's" and the import this decade holds for the science and physics communities. In preparing for this talk I realized it would be one of the last times I could make such a future tense reference. In less than eight months we will be living in the 1990's! Perhaps this realization has lent a sense of urgency to the points I will be making this morning.

The scientific enterprise in the United States is a strong one. Exciting challenges and new scientific developments lie on every horizon. The crucial question is whether we can command the resources to pursue these challenges? When we talk of resources we usually think of research funds and scientific facilities. Equally important, and closely related, are the human resources which form the basic foundation of any scientific endeavor: the teachers, the researchers, the students, and the educated public.

If the scientific enterprise is to continue to thrive, the development and maintenance of a strong resource base of highly skilled individuals is crucial. This has seldom proven to be an easy task. It is becoming more difficult. These human resourses are the ones I will be focusing on this morning.

Let me start by taking a look at some basic demographic and educational trends which underly my concerns. Then we will go on to examine the changes in the physics community which will be interacting with these basic trends, and perhaps exacerbating them.

THE DECLINING YOUTH POOL

As figure one illustrates, 18-24 year olds, the traditional source of college students and physics majors, are projected to decline in number by 25% between 1980 and the late 1990's. Projections are frequently frought with uncertainties. In this case, however, we are on firm ground; these youth have already been born! Also expected is a change in the composition of the youth pool. Indigenous minorities will form an ever increasing proportion of tomorrow's young people. As we will discuss later, the sciences have so far had little success in attracting minorities.

The military was the first area to become concerned with the potential effects of the declining youth pool on their skilled resources; industry and other groups are now also evidencing concern. Simply to retain the current resource levels, more attention will need to be paid to attracting and training youth. Demography, of course, is not destiny, but it does form the boundaries in which we operate.

How well are we doing in attracting students into the physical sciences? The Higher Education Research Institute has been monitoring freshman plans for more than twenty years. Although this is relatively soft data, some clear trends do emerge. Figure two indicates the anticipated college

majors of college freshman over the past decade and a half. The data here reflect percentages; remember, it is likely that these will be applied to a declining pool of students.

The physical sciences draw a very small proportion of students, a proportion which has been on the decline. Even engineering and computer science, technical disciplines which had been on the increase, have come down. Business has been the major growth area over the past decade and a half. Only in the past year does it appear to have reached a peak. Recent patterns of increase are more diverse. In contrast to past years a slightly higher proportion of women students are opting for education and pre-med majors. Among the male students there has been an upsurge in political science, the traditional pre-law major.

To counter these underlying trends, simply to maintain its current human resource base, the science community,-- the physics community,-- will need to make special efforts. To strengthen that base, in order to meet the new challenges and new opportunities which I'll be referring to at the end of this talk, will call for an even more dedicated effort. Let us look at what has been happening in the physics community itself.

PHYSICS PHD PRODUCTION AND THE GRADUATE STUDENT PIPELINE

Figure three presents a very familiar curve: the annual production of physics PhD's in the United States between 1964 and 1989. This production increased rapidly through the 1960's, reaching a peak at over 1500 new PhD's in the early 1970's. The decline in production in the latter part of that decade was as dramatic, falling to 900 PhD's by the start of the 1980's. As the decade wore on a slow resurgence appeared.

On closer examination, it became clear that the primary source of this resurgence was the increasing representation of foreign graduate students in US physics departments. As figure four indicates, by 1988 40% of the new physics PhD's were foreign citizens, more than double the percentage observed in the early 1970's. Although not as high a representation yet as in engineering, this is considerably higher than in other scientific areas. There has been general consensus that these foreign physics students are extremely bright and able; they can be expected to make important contributions to the discipline of physics in the United States. Some concerns have been expressed regarding this increasingly heavy dependency on foreign students. What if a high proportion return home? What if they don't come? (an issue which takes on added importance with the recent developments in mainland China--the primary source of foreign physics graduate students.)

The major concern, however, is not with the increasing representation of foreign students, but rather with the decreasing representation of US students. Figure five, which looks at the absolute number of first year graduate students in physics, presents a clearer picture of what has been occurring. Virtually the entire increase in beginning graduate students has been fueled by the entry of foreign nationals. US students, on the other hand, have either been declining in number or staying stable. The most recent 1989 data point, not yet published, indicates a downturn both in the total number of first year graduate students and, particularly, in the US component. One should not, of course, make too much of a single data point. However, it does prompt us to look

back into the pipeline, to determine how many US students are coming through.

While the number of first year US graduate students in physics was decreasing or stable, the physics bachelors, many of them aimed directly at employment in engineering and other technical areas, had been on the increase. As figure six indicates, this increase has apparently peaked. The number of senior majors has been down two years in a row; the number of junior majors (not pictured) has been down three years running.

We had difficulty drawing US physics majors into graduate school when their numbers were on the increase. They sought out the proliferating engineering jobs instead. What lies in the future, as even this source threatens to shrink? I won't take you back into the high schools today, but they provide us with little reason for confidence.

ALTERNATIVE US SOURCES

So far we have been talking about traditional sources of supply; for physics this means white males. Some graduate areas, particularly in the bio-sciences, have seen a large influx of women during the past decade. In physics, however, women still represent a very small percentage of new PhDs, under 10%. As figure seven indicates, this percentage has been slowly increasing. When the rather sharp 1984-85 increase was first noted, there was considerable excitement. Closer examination, however, indicated that, as with overall PhD production, this upsurge, too, was due primarily to the increased involvement of foreign citizens. This is most clearly shown in figure eight which examines the number of PhDs in physics earned by US and foreign women. Due to the variability in dealing with small numbers two year averages were used. In the most recent year, 1988, the number of foreign women continued to increase to 68, while the number of US women PhDs actually dropped to 57. For the first time, over half of the new women Physics PhDs were foreign.

I am frequently asked why this lack of involvement of US women in physics? There are a wide variety of reasons; that is clearly the subject of another talk. One which may be noted here, however, is the clear absence of role models in the graduate milieu. Over half of the PhD granting physics departments have no women among their physics faculty; another third have but one.

If the involvement of women in physics has been meager, the situation of indigenous US minorities is even more dismal. A single overlay is illustrative; note the scale used here. Combined, US Hispanics, Blacks and American Indians represent only about two percent of new PhDs in physics, a low percentage shared by other fields of mathematics and physical science. Most striking is the fact that this percentage is virtually unchanged over the past decade.

The shrinking youth population I described at the beginning of this talk will increasingly be composed of US indigenous minorities. Will we be more successful in attracting these youths than we have been in the past?

OPPORTUNITIES

The constrained sources of supply, which I've been focusing on in this presentation, are but one part of the picture. There are also the increasing opportunities, potentially escalating demand across many areas. Let me focus, briefly, on a couple of these which are close to the heart of the physics community.

New faculty positions in physics have been tight for nearly two decades now. In the mid 1980's assistant professors represented only 13% of physics faculty, the lowest level among the scientific fields; most of the faculty had been hired during the rapidly expanding period of the 1960's and were now tenured full professors. As figure eleven indicates, the bulk of the physics professoriate is aging, moving ever closer to the retirement years.

Several years ago we carried out a series of supply and demand projections for the Brinkman Physics Survey Committee. Figure twelve illustrates our age projections for the university physics professoriat. The median age rises to over fifty as the decade of the 1990's begins. (Depressed hiring has produced an actual aging in the 1980's which has been even more rapid than initially projected.) In the 1990s massive retirements will begin; in some individual universities they already have. Academic demand will increase.

While there was considerable interest in the projections, there was equal interest in what the current demand situation in academe was, and particularly with how this demand varied by physics subfield. Realizing that such baseline information would take on increased import in the future, we and the American Physical Society POPA committee conducted a survey of faculty availability, first in 1986 and again in 1988. The survey indicated, as expected, that positions in academe were still tight; only a limited number of positions were available. However, even within this tight market, many university chairs deemed the supply of qualified candidates in such areas as experimental condensed matter and atomic, molecular and optical physics as clearly inadequate. If problems in filling positions were already arising when only a relatively small number were available, what would it be like when a large number of positions needed to be filled in the coming decade?

Opportunities in physics will not only lie in the academic sector. During the past decade more and more physics PhDs have found challenging work in industrial employment. Figure fourteen illustrates this rapid increase in industrial involvement. As the academic sector seeks new faculty in the 1990's it will be in direct competition not only with industry, but also with the government and national laboratory sectors. These areas, which are more heavily dependent on US citizens, are already experiencing some difficulties in satisfying their staffing needs.

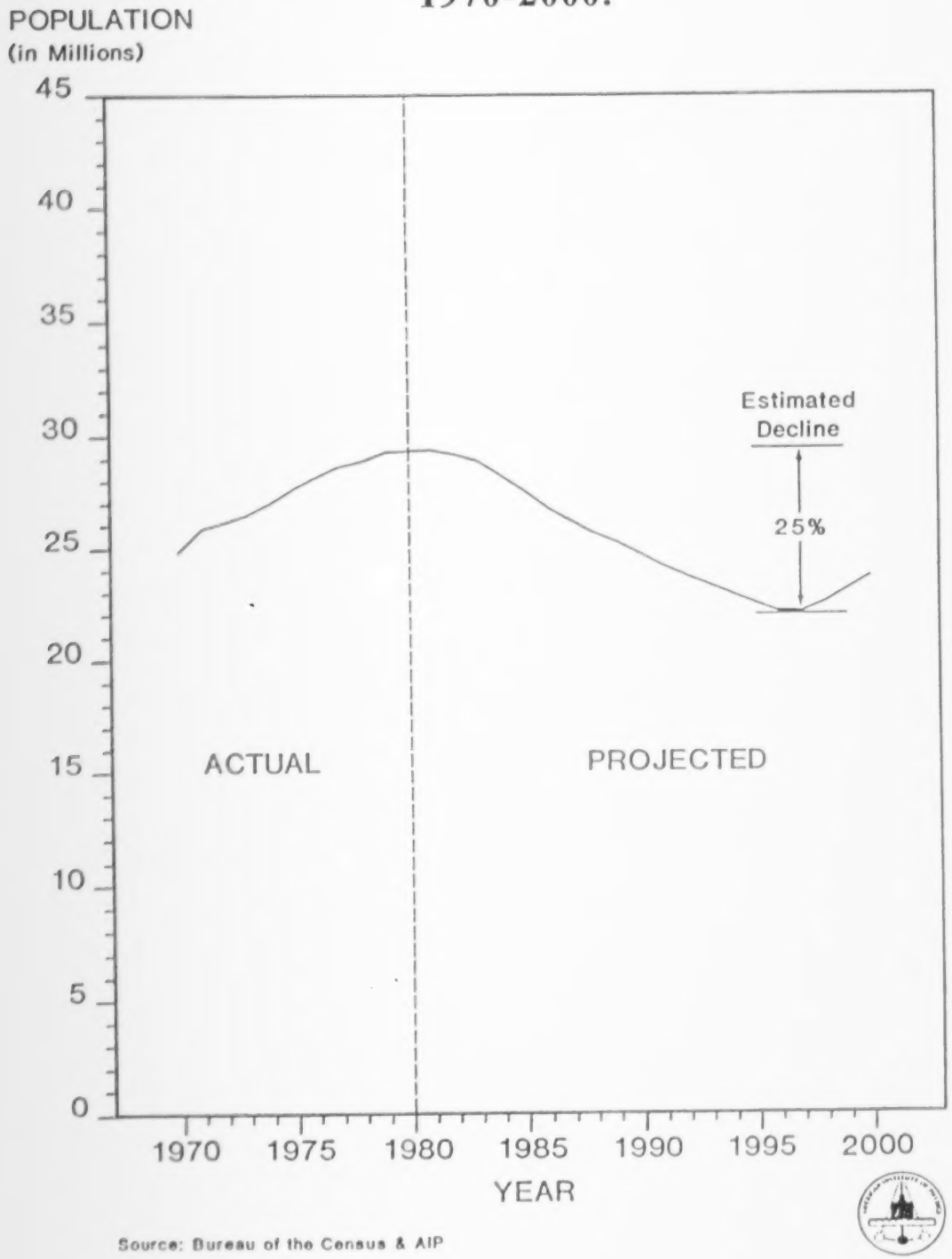
We've been talking here only about internal competition within the physics community. Just as academe does not stand alone, neither does physics. A shrinking resource base of talented youth means competition from many areas: other sciences, the professions and business. It is a given that the absolute number of youth will decline. Fortunately, it is not a given that the number of educated and scientifically trained youth will decline.

CONCLUSION

Competition is a positive force if it pushes us to expand the system, to strengthen the human resource base in the sciences. It is a destructive force if we end up struggling over a diminished pie, a shrinking resource base. Time is short. So much needs to be done! If I'm still giving these presentations at the end of the 1990's, trying to look into the next century, I hope the trends I describe will be more positive than the ones I've shown this morning. Whether they will be or not is, to a large extent, up to all of you sitting in the audience today.

Fig. 1

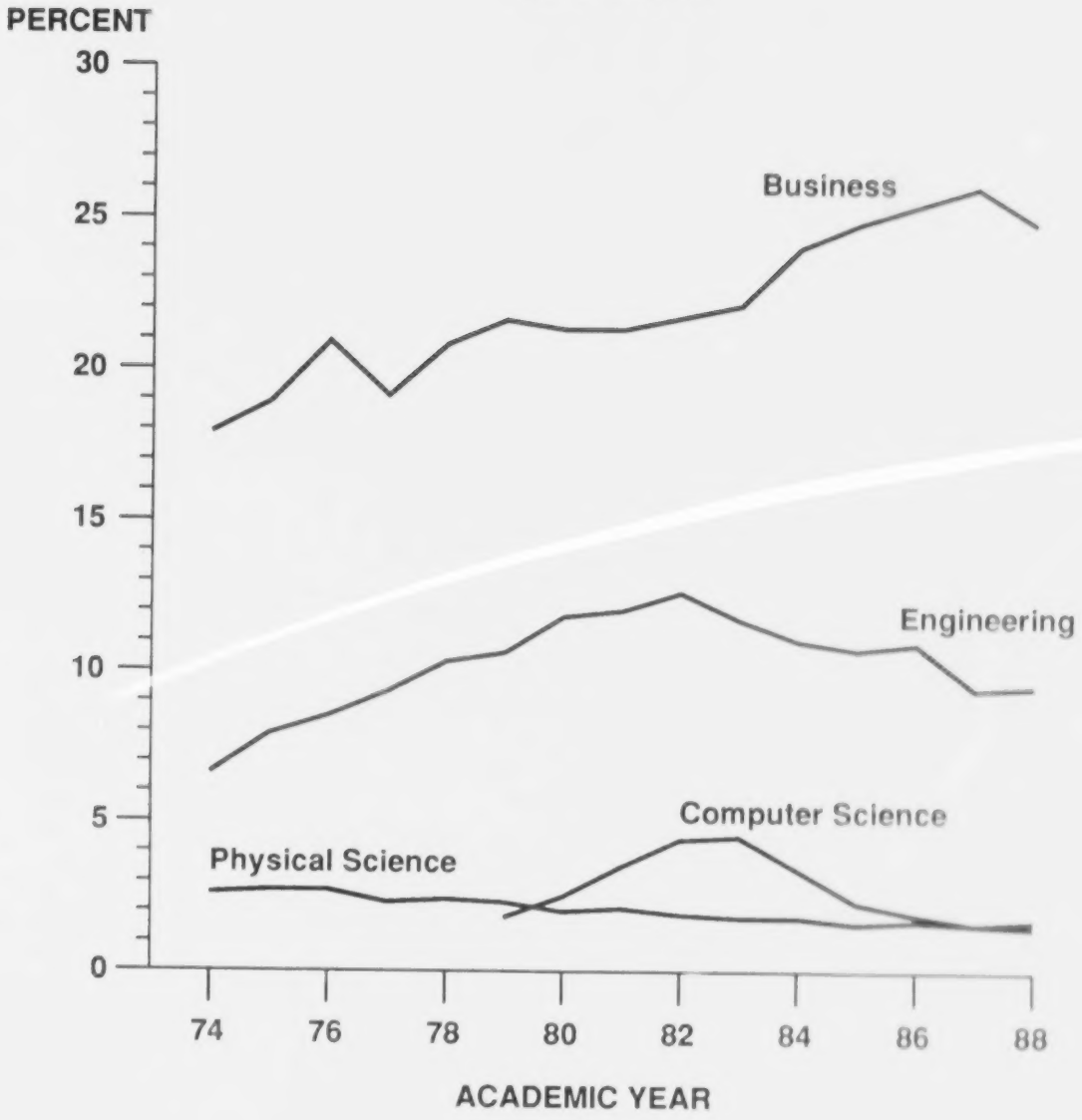
NUMBER OF 18-24 YEAR OLDS: ACTUAL AND PROJECTED, 1970-2000.



Source: Bureau of the Census & AIP

Fig. 2

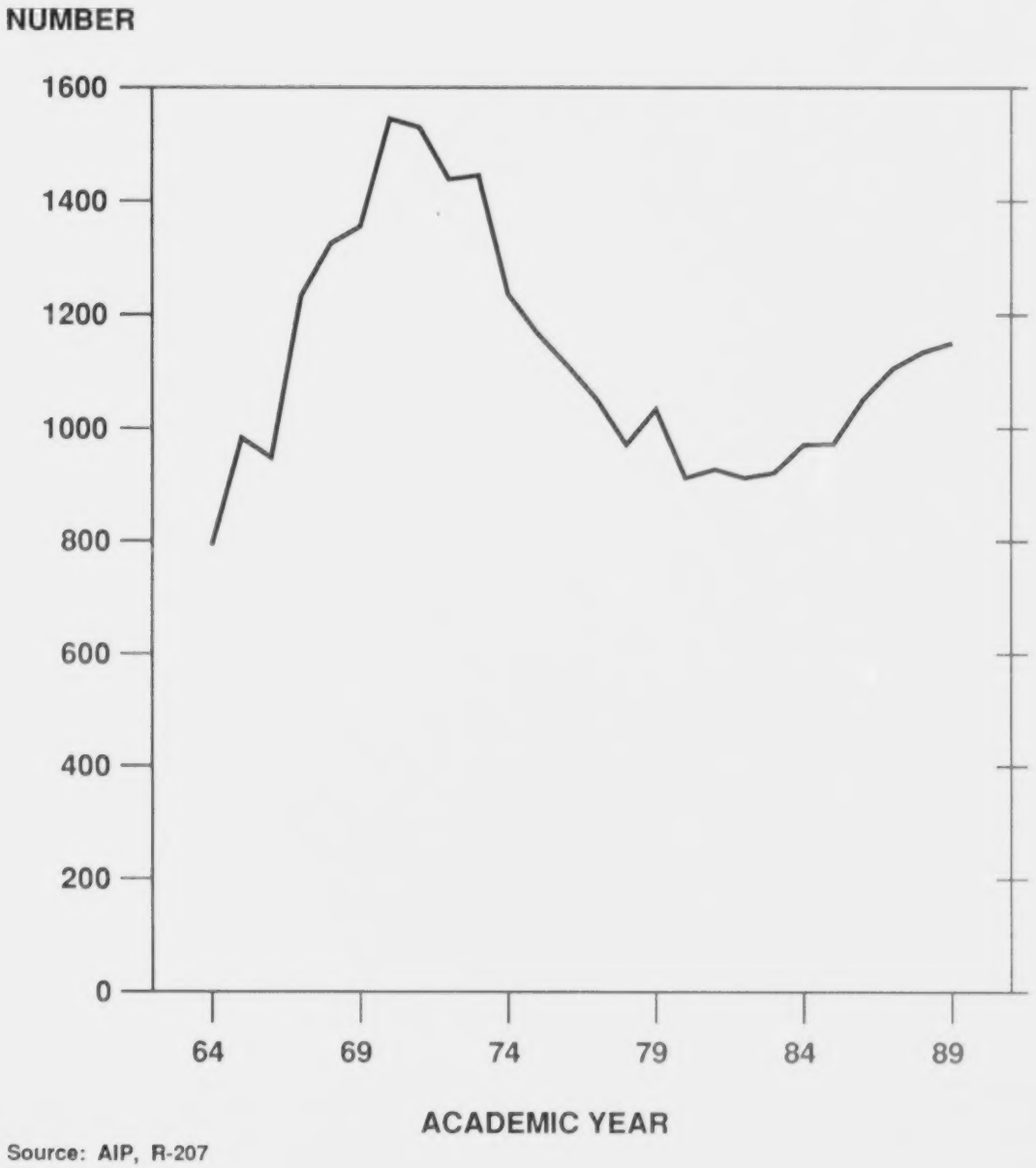
ANTICIPATED COLLEGE MAJOR OF FRESHMEN 1974-1988.



Source: American Council on Education

Fig. 3

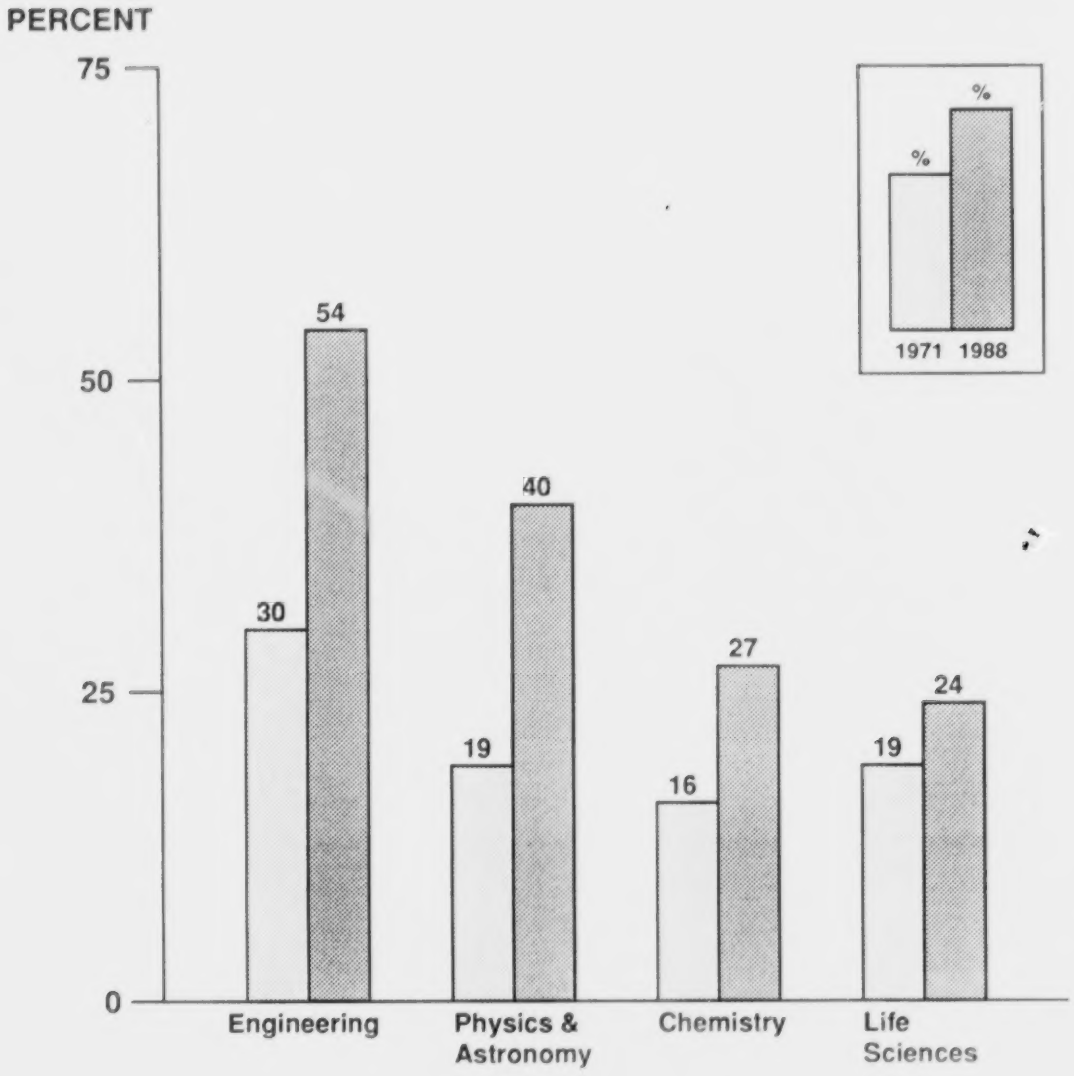
ANNUAL PRODUCTION OF PHYSICS PHDS IN THE U.S., 1964 - 1989.



Source: AIP, R-207

Fig. 4

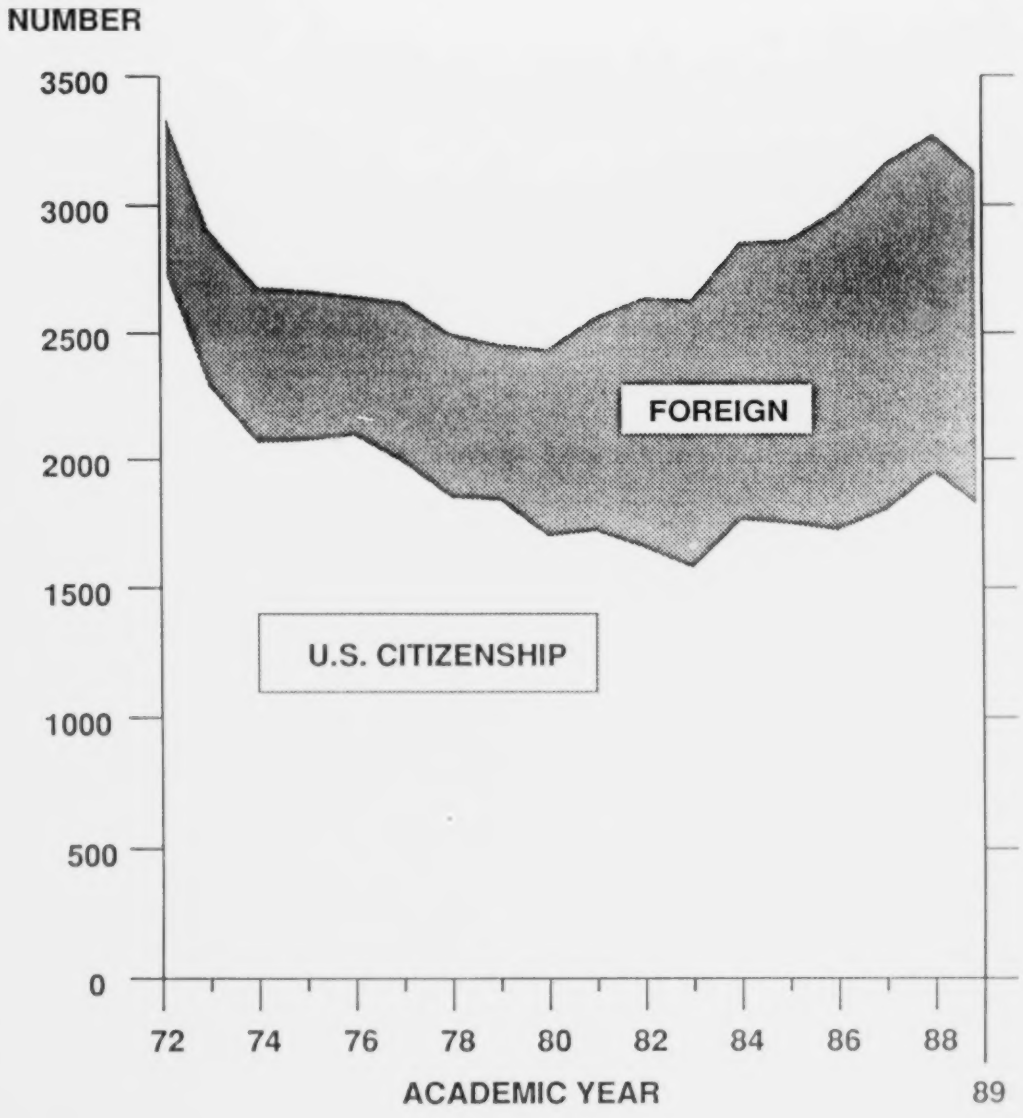
PERCENT OF NEW PHDS AWARDED TO FOREIGN CITIZENS, 1971 AND 1988.



Source: NSF & NAS prepublication data

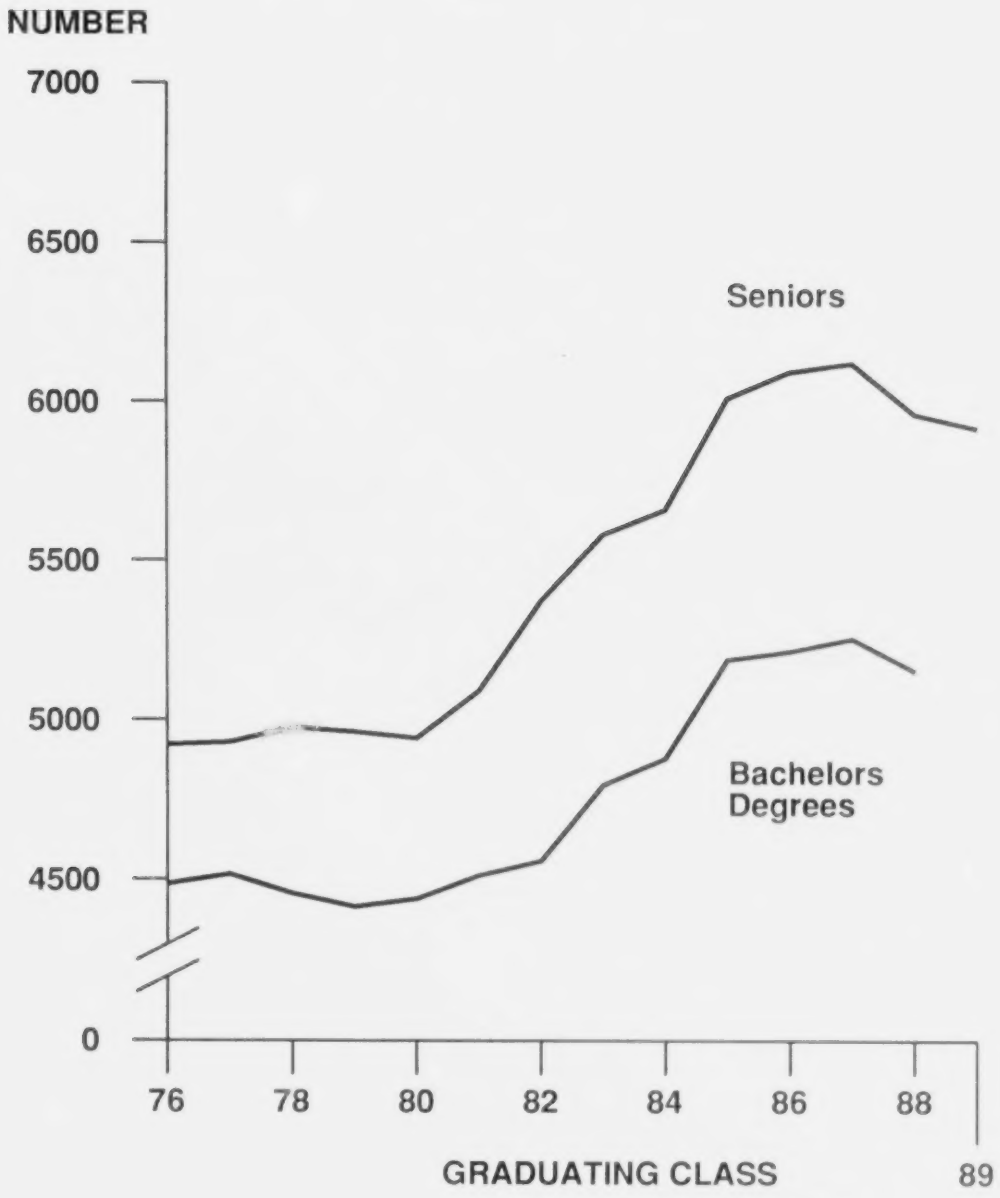
Fig. 5

FIRST YEAR GRADUATE PHYSICS STUDENTS BY CITIZENSHIP, 1972-1989.



Source: AIP, R-151

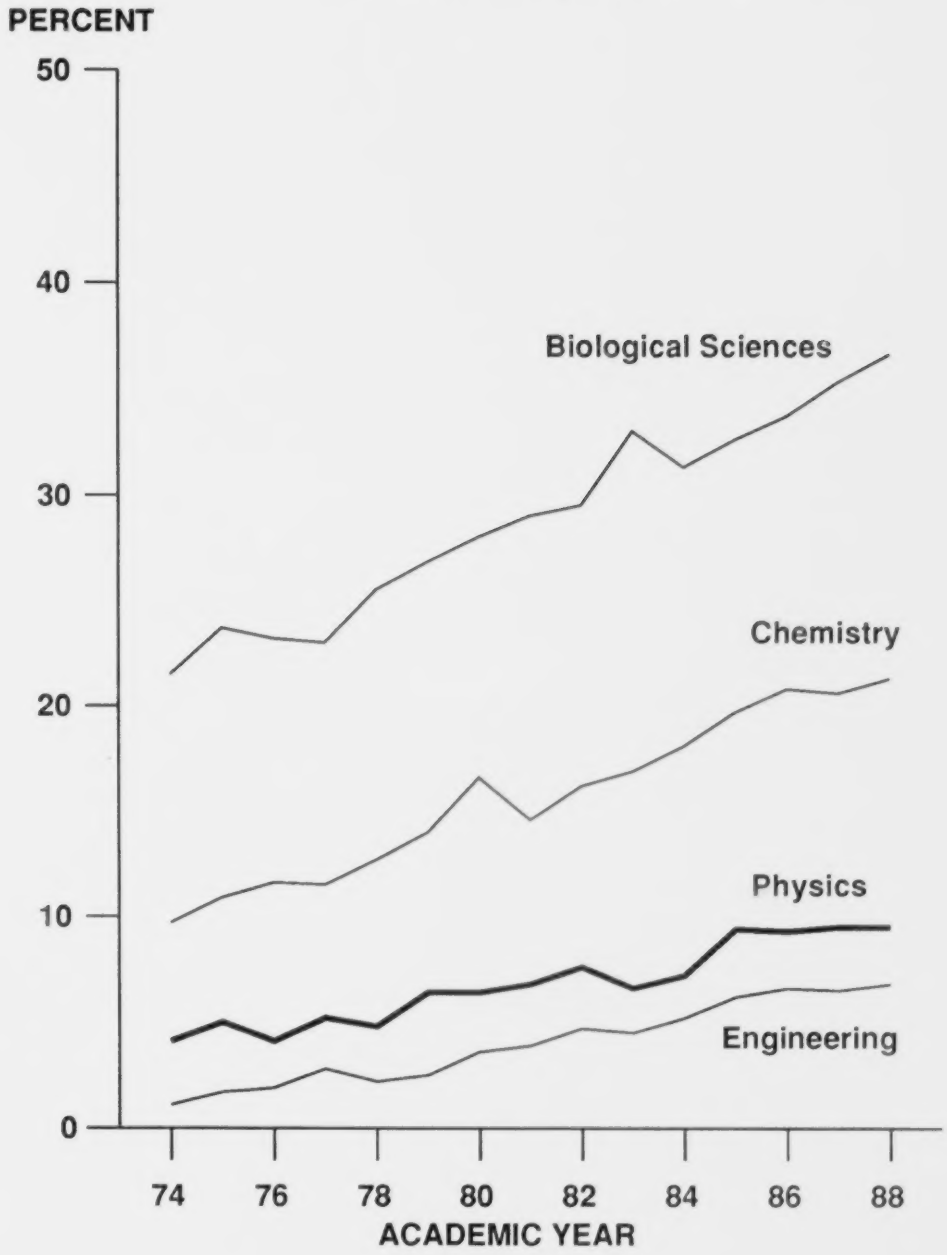
Fig. 6 **SENIOR ENROLLMENTS AND BACHELORS DEGREES AWARDED, 1976-1989.**



Source: American Institute of Physics

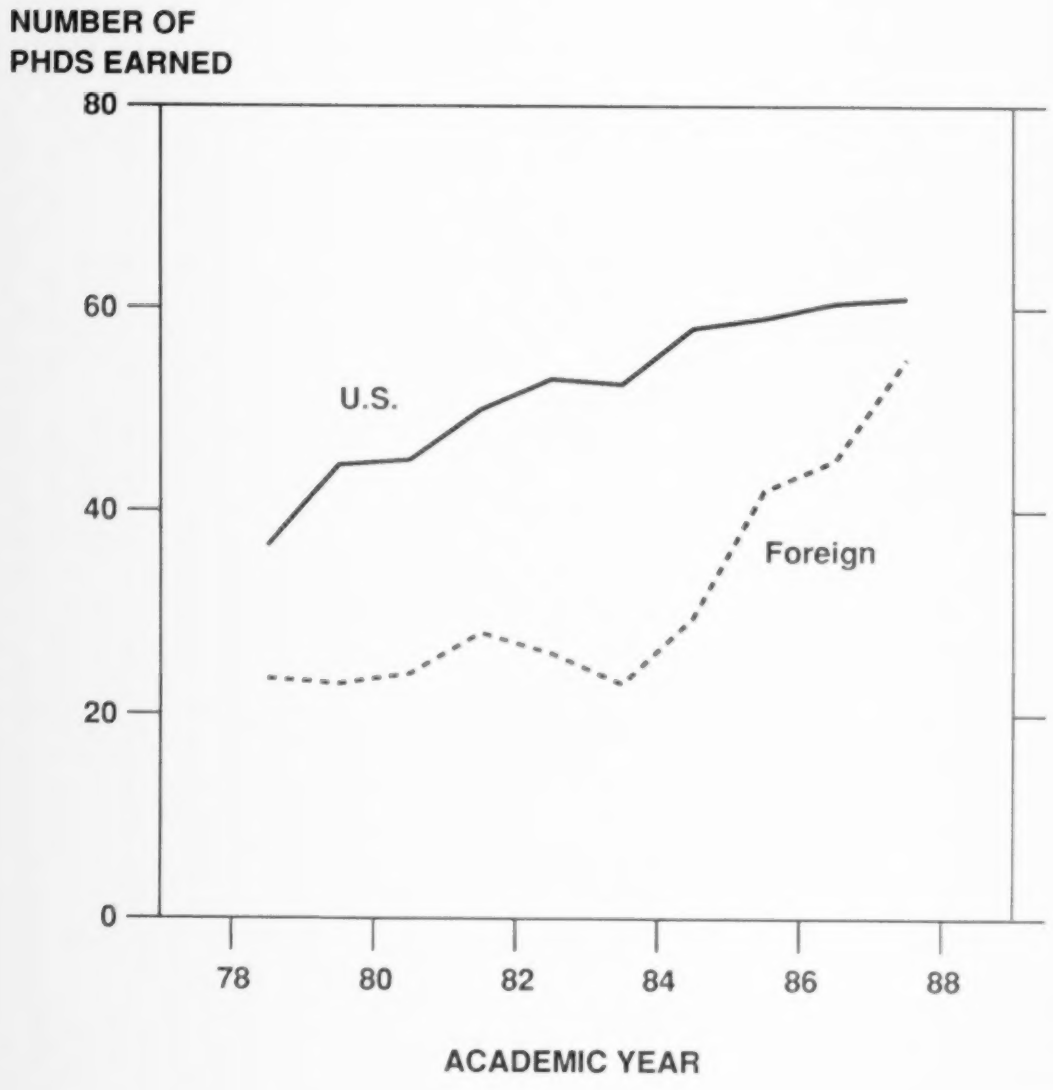
Fig. 7

PERCENT OF PHDS AWARDED TO WOMEN, 1974 - 1988.



Source: NRC & NSF

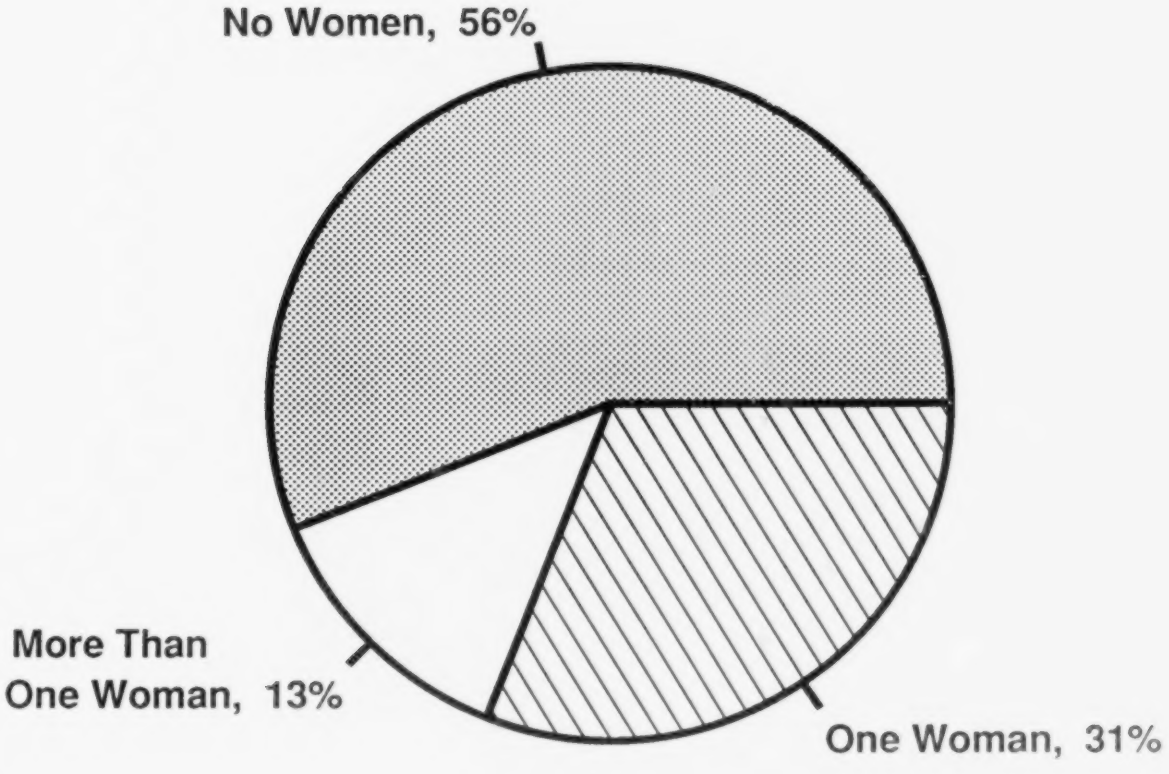
Fig. 8 ***PHYSICS AND ASTRONOMY PHDS GRANTED TO WOMEN BY CITIZENSHIP, 1978 - 1988.***



Source: NAS & NSF
Curve smoothed using two-year averages.

Fig. 9

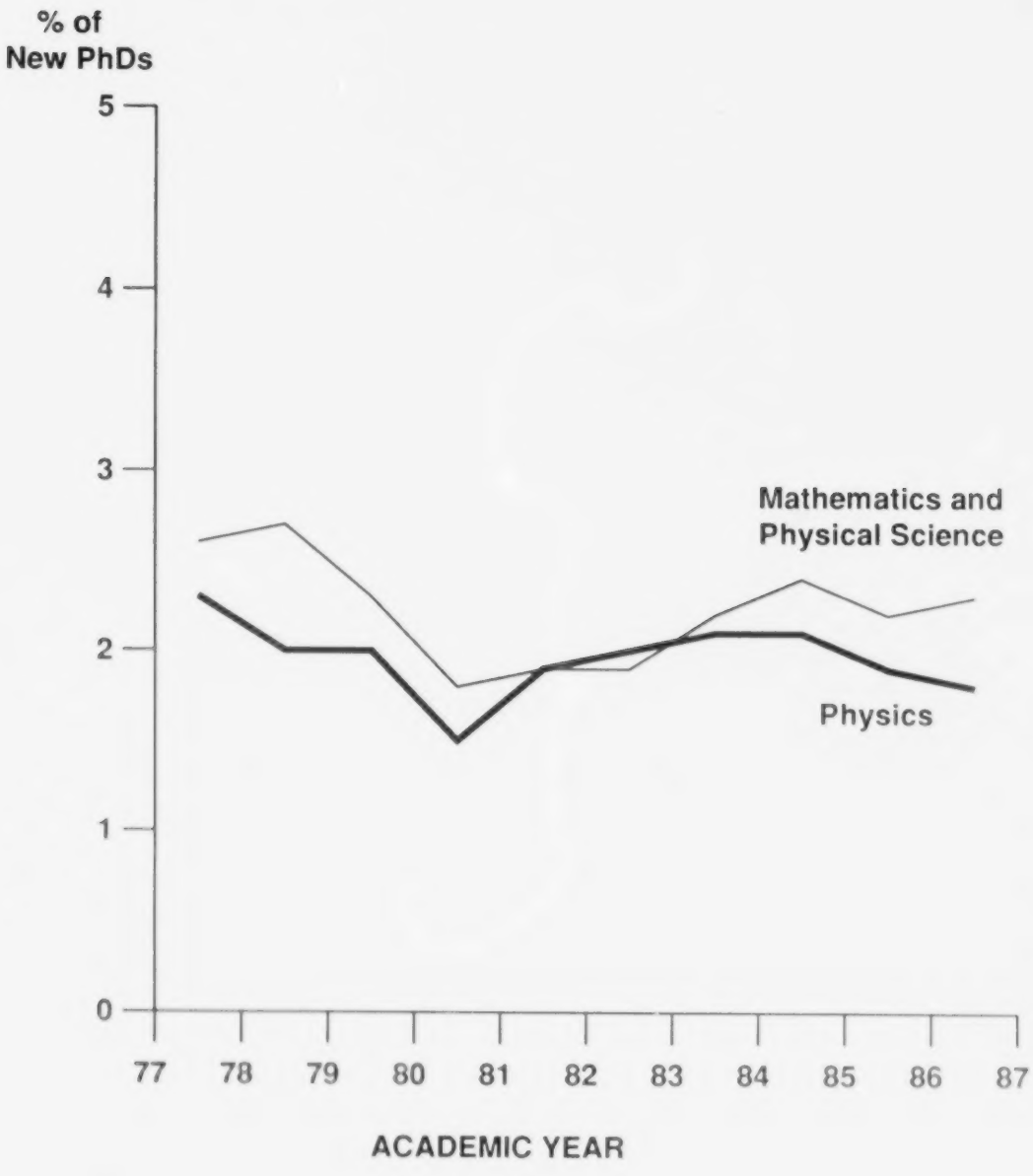
WOMEN PHYSICS FACULTY IN PHD GRANTING DEPARTMENTS



Source: AIP, unpublished data

Fig. 10

U.S. HISPANICS, BLACKS, AND AMERICAN INDIANS AMONG NEW PHDS, 1977-1987.

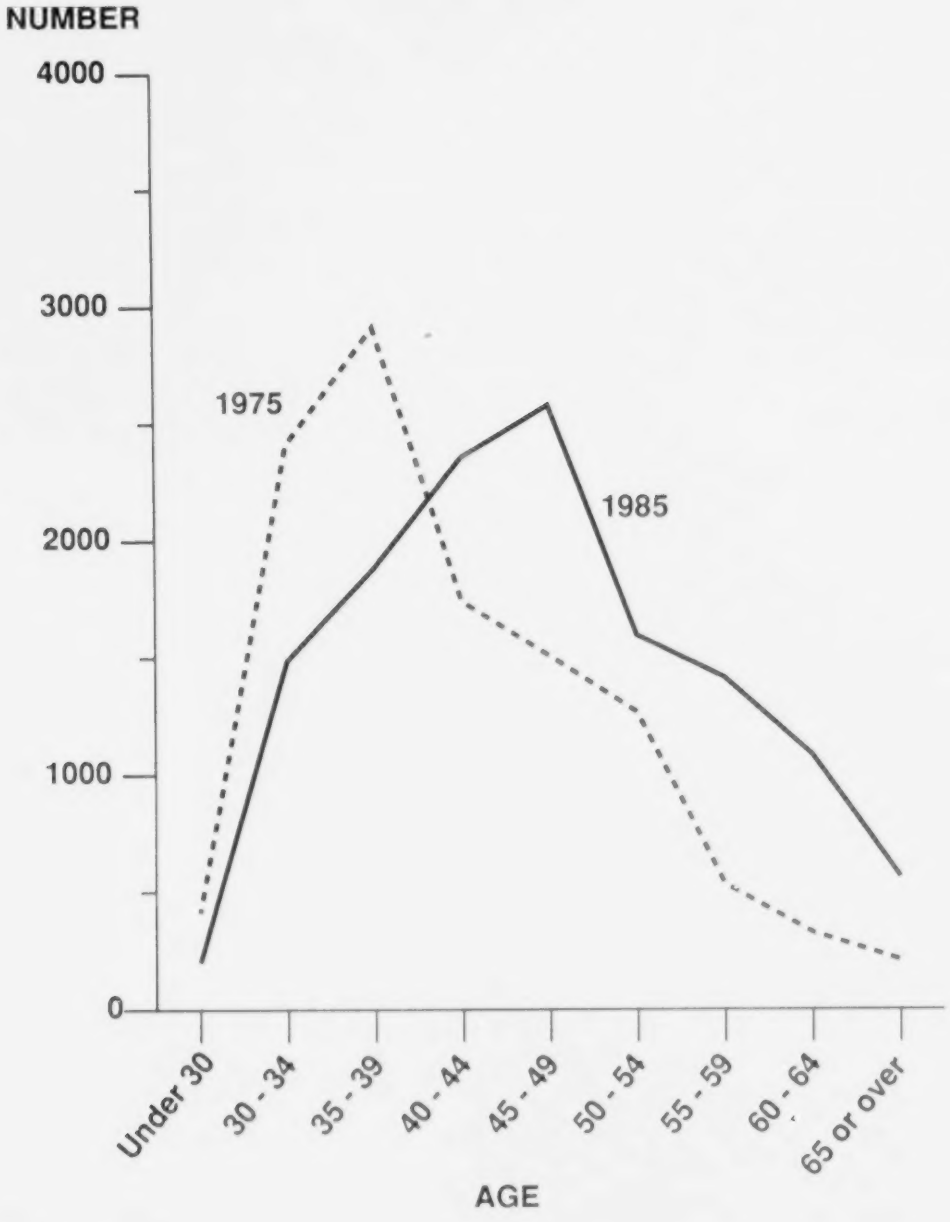


Curve smoothed using two-year averages

Source: NAS

Fig. 11

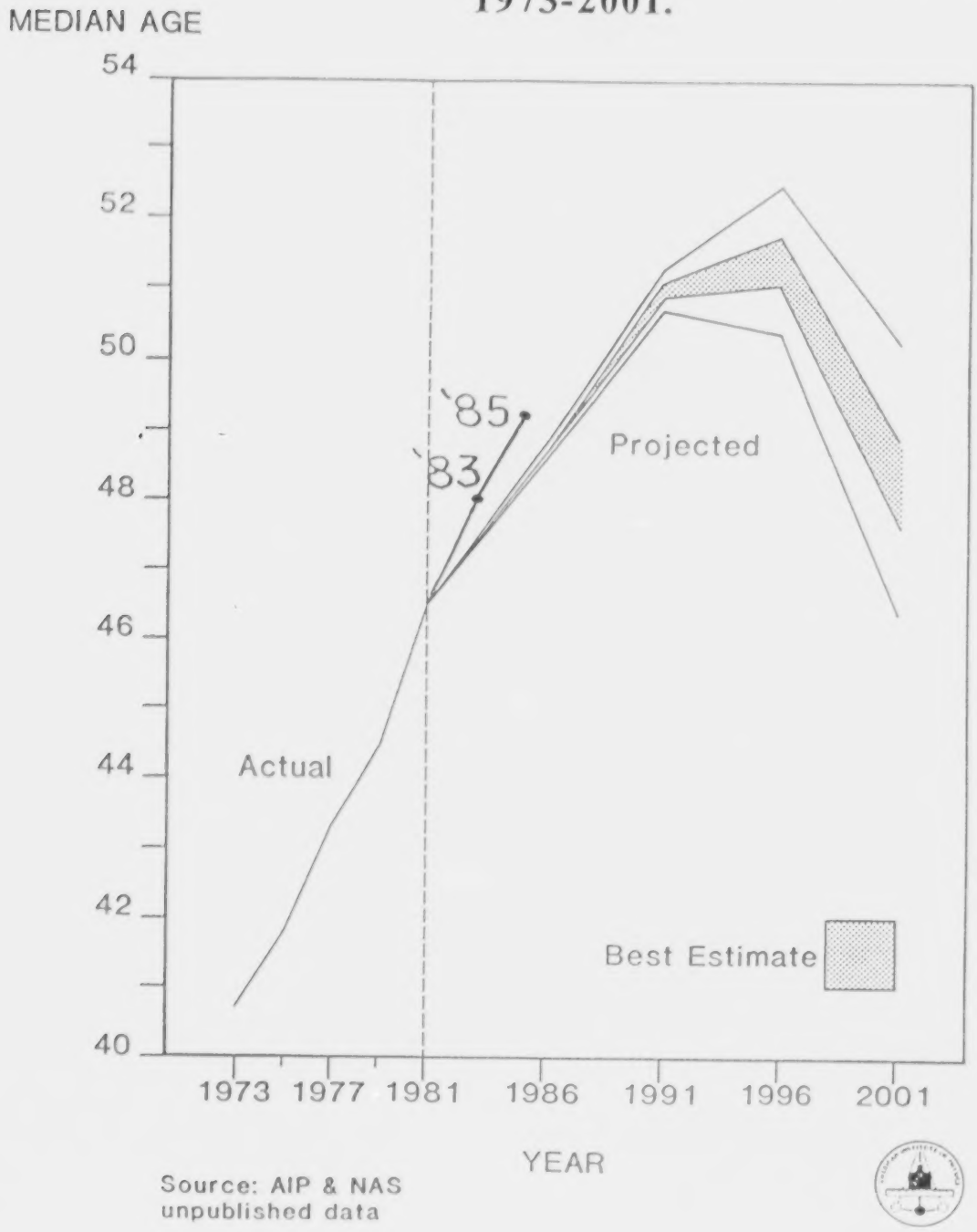
DOCTORAL PHYSICISTS EMPLOYED IN UNIVERSITIES AND FOUR-YEAR COLLEGES BY AGE, 1975 AND 1985.



Source: NSF

Fig. 12

MEDIAN AGE OF UNIVERSITY PHYSICS PROFESSORIAT: ACTUAL AND PROJECTED, 1973-2001.

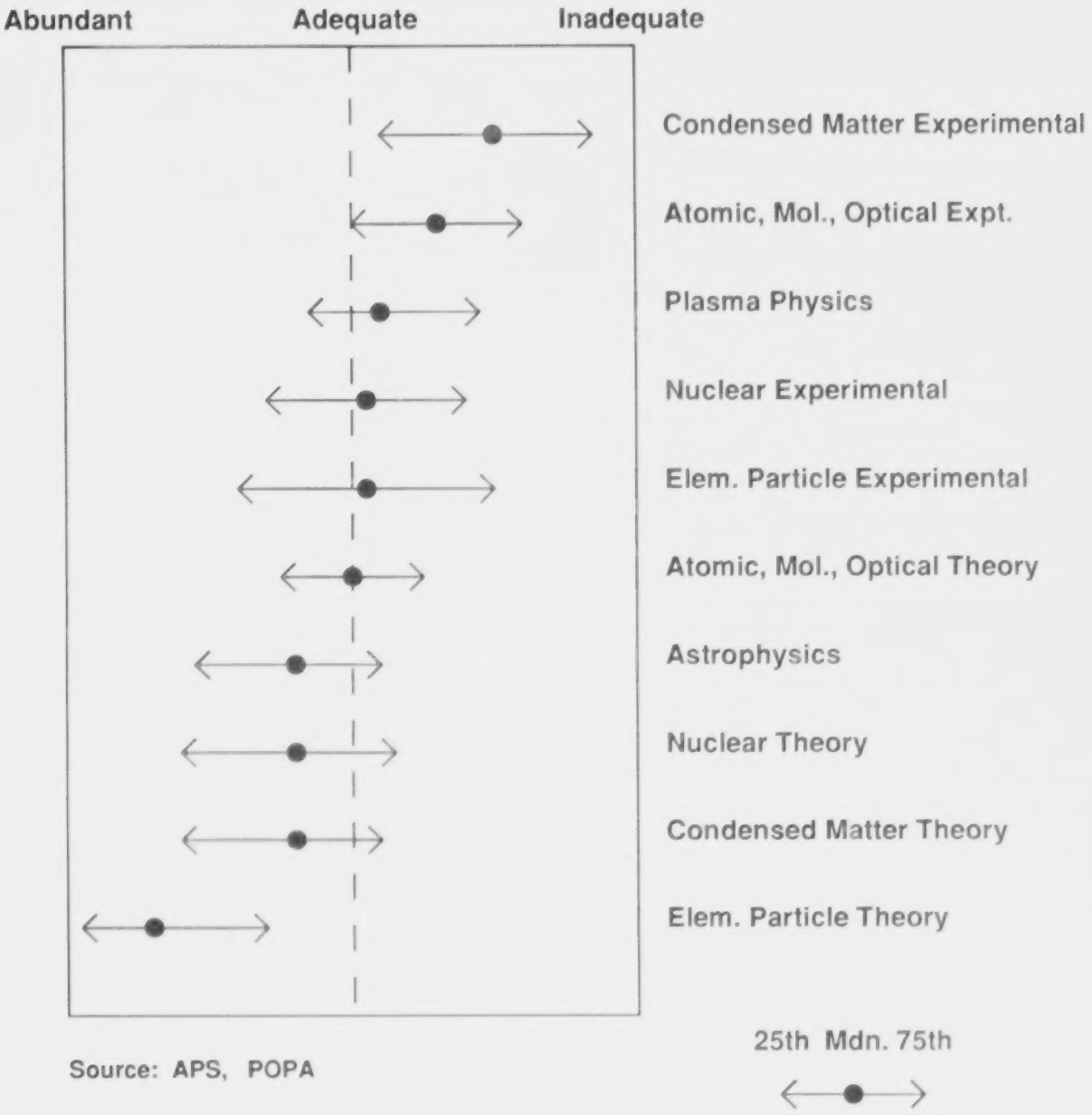


Source: AIP & NAS
unpublished data

Fig. 13

SUPPLY OF CANDIDATES IN SELECTED PHYSICS SUBFIELDS

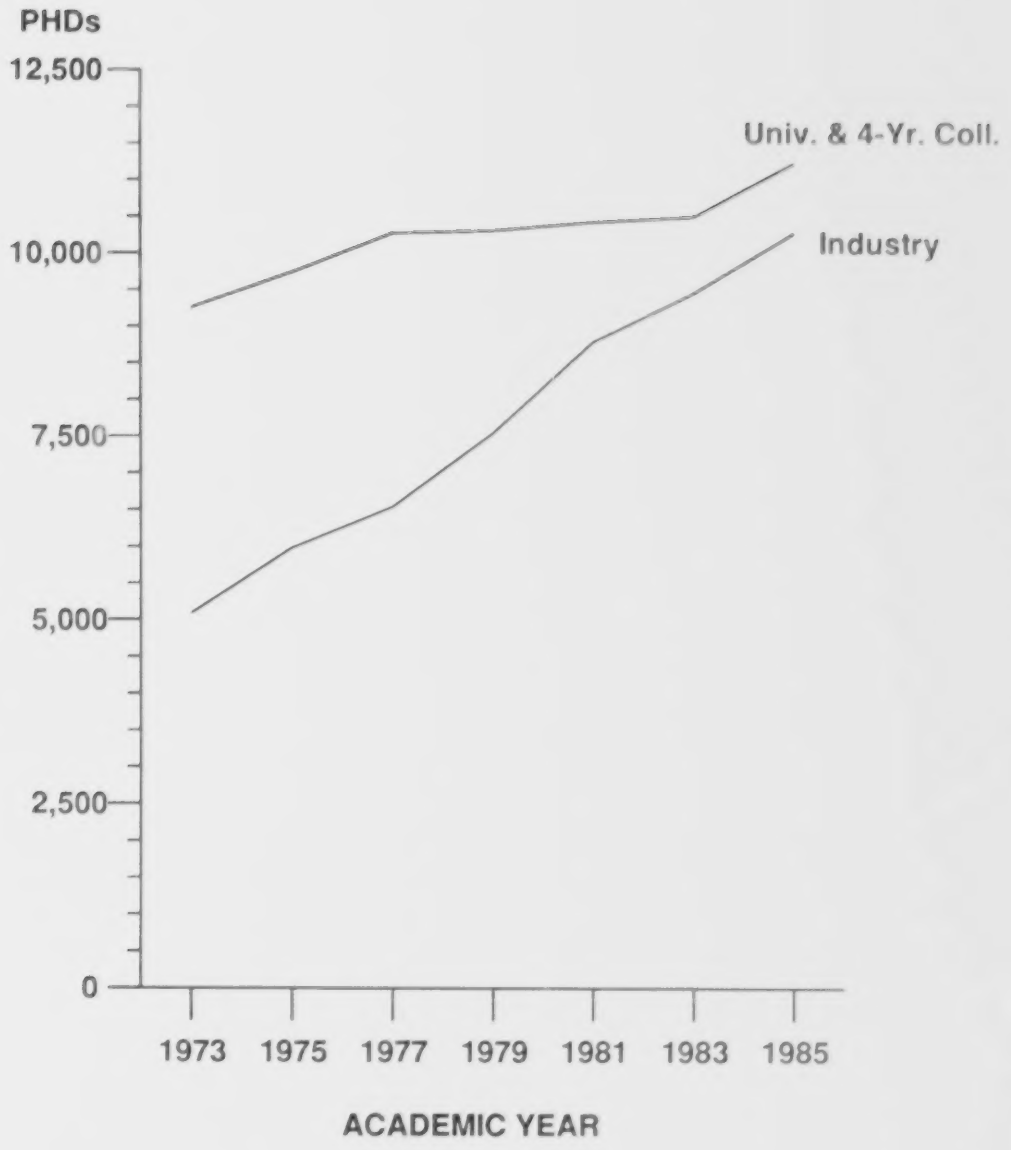
Ratings by University Chairs, 1988



Source: APS, POPA

Fig. 14

PHYSICS PHDS EMPLOYED IN ACADEME AND PRIVATE INDUSTRY, 1973-1985.



Source: NAS, unpublished data

Rethinking the Stanford graduate curriculum in physics

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1. Introduction and background

For the past several years, the physics community at Stanford has reviewed and revised our graduate curriculum. This process has been both arduous and rewarding; only recently have the results of this effort begun to take tangible form. We recognize that many other institutions are undertaking similar reviews; in the hope of providing some guidance and advice, I shall attempt to recount the various steps that we used and to summarize our conclusions.

It is necessary first to understand a little about the organization of physics at Stanford. Physics, broadly defined, is the principal concern of the Departments of Applied Physics (18 faculty members [these and subsequent numbers include research faculty]) and Physics (24 faculty members). In addition, the Stanford Linear Accelerator Center (SLAC, 30 faculty members) and the Stanford Synchrotron Radiation Laboratory (SSRL) study particular areas of physics, as do certain parts of the Department of Electrical Engineering (EE, about 9 faculty members are involved in physics-related activities). Graduate students are admitted by academic departments, and the total steady-state population is about 280, roughly half in Applied Physics and half in Physics. These students are free to find advisors anywhere within the broadly defined physics community: roughly 30% of Physics graduate students work at SLAC and another 15% work in Applied Physics; similarly, approximately 30% of Applied Physics students work with advisors in Electrical Engineering.

During the winter and spring of 1985, the Physics Department held several open meetings with its graduate students to hear about the graduate curriculum. As a result, the department then undertook a survey of its graduate students to ask about their preparation for specific areas, as well to consider the effectiveness and appropriateness of the first-year graduate courses as then taught. The results were troubling, in that many students felt that the first-year courses were taught at too low a level (for example, they wanted more continuum mechanics, more statistical mechanics, and some relativistic quantum mechanics in the first year). In addition, there were also concerns about the consistency of the syllabus from year to year and the quality of teaching.

At the same time, by chance, the Stanford physics community was exploring how to formulate a more coherent view of its own future. As a result of various discussions, we decided to form a committee to review and revise the graduate physics curriculum. This committee contained both faculty (8 members) and graduate students (10 members),

drawn widely from Applied Physics, Physics, and SLAC. Under the leadership of J. D. Walecka, it met 12 times during the academic year 1985/86 and submitted an interim report in June, 1986. Not surprisingly, the task was too great to complete in one single year, and the committee was reconstituted the following year under the leadership of V. Petrosian (with 8 faculty and 6 student members) to refine and complete the work. Their "Report of the Joint AP/Phys/SLAC Graduate Curriculum Committee, June, 1987" has guided our subsequent plans and actions.

2. The process

At the initial meetings, the committee actively debated its goals; the general view was that we should seek to set the direction of graduate physics education at Stanford for the next decade. To help us in the effort, we focused on the question: "what are we trying to do?" In the course of these discussions, we identified two basic goals of our graduate education:

1. Provide basic technical background in physics. This goal includes ensuring that students understand physics and can use it effectively. As part of the effort, we seek to enable students to attack and solve a variety of problems in many different fields.

2. Bring students to the level where they can make creative contributions to forefront research activities at Stanford (and elsewhere, after they complete their graduate degree).

Our first step was to identify a common core of material that all graduate students in physics should cover in the first-year courses. To help in this process, we studied the current graduate curriculum from a selected group of research universities: Berkeley, Cal. Tech., Chicago, Cornell, Harvard, MIT, Northwestern, and Princeton. Copies of the relevant material from their catalogs were distributed to the members of the committee for consideration and for analysis.

Our second step was to identify the major areas of physics research at Stanford, including all constituencies. The aim was to ensure that we emphasize our current strengths in research, rather than trying to cover all areas. As a result of these considerations, five general areas were selected:

AMO/quantum optics
Condensed matter physics (CMP)
Gravity/astrophysics
Nuclear physics
Particle physics

Ideally, we sought to cover each of these fields at two separate levels: first, a one-quarter introduction to each field (suitable for a nonexpert first-year graduate student who will not go on in that field), and second, a unified advanced set of courses in each area (typically two quarters, at the level of a second-year graduate student). To plan such a specific

curriculum, we set up five subcommittees, one for each field, consisting of students and faculty in the field (typically 4-6 members in all, including a few co-opted members who had not been part of the parent committee). Each subcommittee was charged to consider the totality of courses offered at Stanford in their field, including courses that were not traditionally utilized by physics students. This latter part of the charge was designed to investigate overlap with related courses in other departments and schools.

Our final step, as a committee, was to identify a wish-list of specific additional courses that we wanted but that lie outside the previous framework. Our initial discussion identified the following list:

Accelerator physics
Computational physics
Experimental course on laboratory electronics
Nonlinear physics and chaos.

It was an educational process for all of us. We discovered many relevant courses in the School of Engineering. In addition, the meetings provided a unique opportunity for collegial interactions at all levels (students headed some of the subcommittees). In retrospect, the process of discussing and defining a common graduate curriculum helped to develop a sense of the physics community at Stanford.

3. The recommendations

The initial recommendations were made at the end of the first year (1985/86), and they were reviewed and refined by a reconstituted committee during the second year (1986/87). They cover four specific areas:

CORE COURSES: These are basic first-year graduate courses that are considered essential in all areas of physics. The basic plan is a modified form of then current practice (note that Stanford uses a quarter system):

Year I	FALL	WINTER	SPRING
	quantum mech	quantum mech	quantum mech
	classical mech	classical mech	statistical phys
	electrodynamics	electrodynamics	menu of intro. courses:
			AMO
			CMP
			grav/astro
			nucl phys
			part phys

There was general perception that the first-year curriculum needs to be agreed upon and stable. Subsequent second-year courses must be able to assume that the relevant material was indeed covered. In addition, we recommended adding a two-quarter laboratory sequence on electronics and instrumentation for physics research, nominally as part of the first-year curriculum, but open to any physics-oriented graduate student. Equipping such a course will require considerable funds.

A few notes on the "standard first-year courses": Quantum mechanics should include relativistic one-body equations--the Dirac equation and the Klein-Gordon equation, the Dirac hydrogen atom, introduction to second quantization for the radiation field, and the interaction of radiation with matter. Classical mechanics should compress particle mechanics to roughly half the first quarter, adding an introduction to continuum mechanics in the first quarter and including the behavior of nonviscous and viscous fluids in the second quarter, along with an introduction to nonlinear systems and the modern picture of chaos.

A new graduate level course on computational physics would be very desirable. In hindsight (1989), we would now urge that students acquire facility with desktop computers, particularly with numerical analysis at the level of "Numerical Recipes," W. H. Press et al., Cambridge University Press, 1986 (which had not been widely available when the committee was at work).

For theorists in almost any field (and for many experimentalists), a year-long course on quantum field theory constitutes part of the core. Well-prepared students take it their first year, but most students prefer to wait until they have taken the first-year sequence in quantum mechanics.

SUB-DISCIPLINES: The rapid growth of physics makes it impossible to acquire a broad knowledge of all areas. To combat the pressure for early specialization, and to allow students (both theoretical and experimental) to acquire a reasonable knowledge of several areas outside their own research field, we have instituted a set of five "menu" courses chosen to reflect the active research programs at Stanford; other universities would doubtless have different lists. Their level is to be appropriate for a student at the end of the first graduate year; although these menu courses are listed as a block, it is not expected that a student would take more than one in any given year.

In addition to these five areas, a two-quarter sequence in the physics of particle accelerators was strongly urged and has been implemented.

ADVANCED AND SPECIALIZED COURSES: Over the past decade, many new advanced courses had been added, sometimes in different departments without sufficient coordination. The committee worked hard to review all courses in a given field. In some cases, courses should be modified or combined, and a few new courses should be created to fill previous gaps. The following is a list of recommended courses by sub-discipline.

AMO: Atomic physics
Lasers
Nonlinear optics
Laser laboratory

CMP: Electronic structure
Cooperative phenomena
Theory of condensed matter
Phase transitions and critical phenomena
Condensed matter laboratory

Grav/astro: Solar physics
Stars and galaxies
High-energy astrophysics
Gravitation and cosmology
Astrophysics laboratory

Nuclear physics: Applied quantum field theory
Weak interactions

Particle physics: Basic phenomenology and theory
Advanced topics in particles and fields
Experimental methods in particle physics

TEACHING EVALUATION: The success of this revised curriculum depends on the quality of the teaching, especially in the core courses. The committee made the following comments on the improvement and evaluation of teaching. "If this new graduate curriculum is adopted, it behooves all of the physics faculty at Stanford to make the strongest possible effort to teach it effectively and successfully. Good classroom teaching is a goal which can only be achieved by developing a common spirit and ethos among the faculty (and students) that places good teaching in high regard." They then made several specific recommendations (note that Stanford has mandatory evaluation of every class through a University form near the end of each quarter).

1. The strongest teachers should be assigned to the basic first-year graduate courses.

2. To provide feedback during the quarter, at least one of the following mechanisms should be used each quarter for the core courses:
   a. peer evaluation through classroom visitation
   b. student evaluation through classroom visitation
   c. written student evaluation during the quarter
   d. visit by representative from the Stanford Center for Teaching and Learning

3. Instructors in the core courses should submit a detailed outline to the chairmen of Applied Physics and Physics before the start of each course or quarter to ensure that the requirement for minimum subject matter will be met.

4. Implementation

We are now (May 1989) nearly two years into the implementation of these recommendations. It has involved a massive renumbering of courses, as well as cross-listing of essentially all graduate courses in Applied Physics and Physics. The main difficulty is that the total number of courses considerably exceeds our ability to staff them, even using alternate years for the more advanced courses. One important step in resolving this problem is the agreement that faculty from SLAC and SSRL will teach approximately 12 quarters each year, partly at the graduate level but also partly at the undergraduate level (freeing up other faculty to teach advanced topics).

The revised Stanford physics curriculum already has several solid accomplishments to its credit: The sequence on accelerator physics and the course on computational physics have been offered for the past two years. We have found and allocated the necessary resources for equipment and teaching assistants for the two-quarter laboratory course on electronics and instrumentation, which will be offered in 1989/90. General oversight on these curricular matters is lodged in a Physics Coordinating Committee (2 representatives from Applied Physics, Physics, and SLAC, including the chairs and director, respectively, and one representative from Electrical Engineering) that meets approximately twice per academic quarter to discuss all aspects of the physics program at Stanford.

One corollary is that we should reconsider our current practice of admitting graduate students only to either Applied Physics or Physics. We hope to do so in the near future. As a first step, we are sending a common packet of information covering Applied Physics, Physics, SLAC and SSRL to all students who request Stanford application forms. We hope to prepare a joint brochure describing the physics research activities of these departments and programs at Stanford (along with those in affiliated departments such as Electrical Engineering).

Many of the sub-disciplines have worked together implementing (or modifying, if appropriate) the curriculum along the lines recommended, but we still need to do more with several of the advanced sequences. Specifically, we continue to seek increased sensitivity to the needs of the broader Stanford physics community as opposed to those of particular research groups. This process will necessarily be an ongoing one as new faculty are appointed. We estimate that about eighty percent of the recommendations are now in place, and it will take a few more years of experience before we can evaluate the full impact of our efforts.

Acknowledgment: I am grateful to M. R. Beasley (Chair, Applied Physics) for helpful comments and suggestions on this manuscript.

Trends in Physics Graduate Education at MIT

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Abstract

We discuss trends in faculty and, most especially, graduate student statistics at MIT over the last decade. The most striking feature is that there are no marked trends except for the increase in the percentage of foreign nationals among our graduate body. As a corollary this means that certain problems including the participation of underrepresented minorities in Physics have not been ameliorated.

I. Introduction

The Physics Department at the Massachusetts Institute of Technology (MIT) is one of the largest in the United States. Concomitantly, we have one of the largest Physics Ph.D. programs with about 270 Ph. D. candidates and ~ 45 Ph. D.'s awarded per year. We also have ~ 20 terminal Master's degree candidates. Our department has significant research and teaching activities in virtually all frontier areas of physics including astrophysics, atomic physics and quantum optics, biophysics, condensed matter physics, elementary particle physics, nuclear physics and plasma physics. Thus our department represents a microcosm of physics graduate education in the United States.. As we shall discuss, our departmental statistics are closely similar to the corresponding national figures except in certain significant areas including the number of women faculty members and the number of underrepresented minority Ph. D.'s In this article we review the basic statistics

with emphasis on the last decade and with some projections for the next decade. We also discuss various problems the department faces and suggest possible solutions.

II The Statistics

The total number of physics faculty at MIT and their distribution among the various academic ranks are shown in Fig. 1. As is evident from the figure, our faculty experienced a remarkable growth between the years of 1961 and 1968 reaching a maximum of 105; this growth period was followed by a graduate declination to the current value of 88. We anticipate that over the next five years the faculty will decrease further in size to about 85. There will however be a net increase in the number of faculty in the assistant and associate professor ranks as senior faculty retire. It is difficult to project the ultimate size of our department although it is unlikely to be less than 80. This declination, which has direct impact on the size of our graduate student body, is directly related to the increasing reluctance of federal funding agencies to provide academic year salary support.

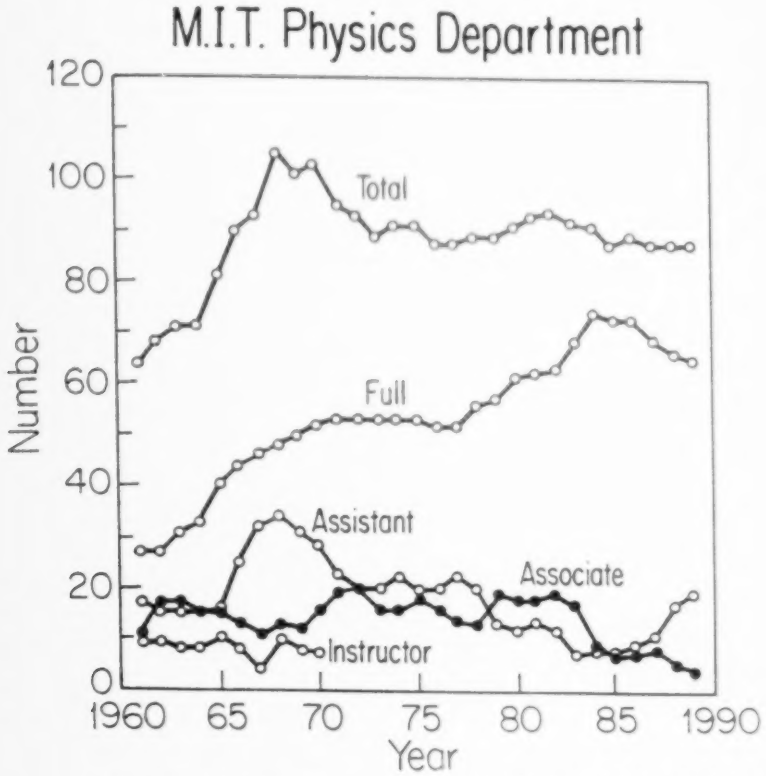

Figure 1. Total number and numbers by rank of faculty in the Department of Physics at MIT over the last 30 years.

The total number of graduate students together with the numbers of foreign national, women and underrepresented minority students is shown in Fig. 2. It is evident that for the last decade the total number has been constant at about 290 with the fluctuations being well within one standard deviation. This constancy reflects the effects of a combination of a nearly constant faculty size together with a consistent level of funding for research. The average number of graduate students per faculty member is 3.3. About 75% of the students are doing experimental theses, whereas approximately 60% of the faculty are experimentalists. This difference arises from two factors. First, experimentalists tend

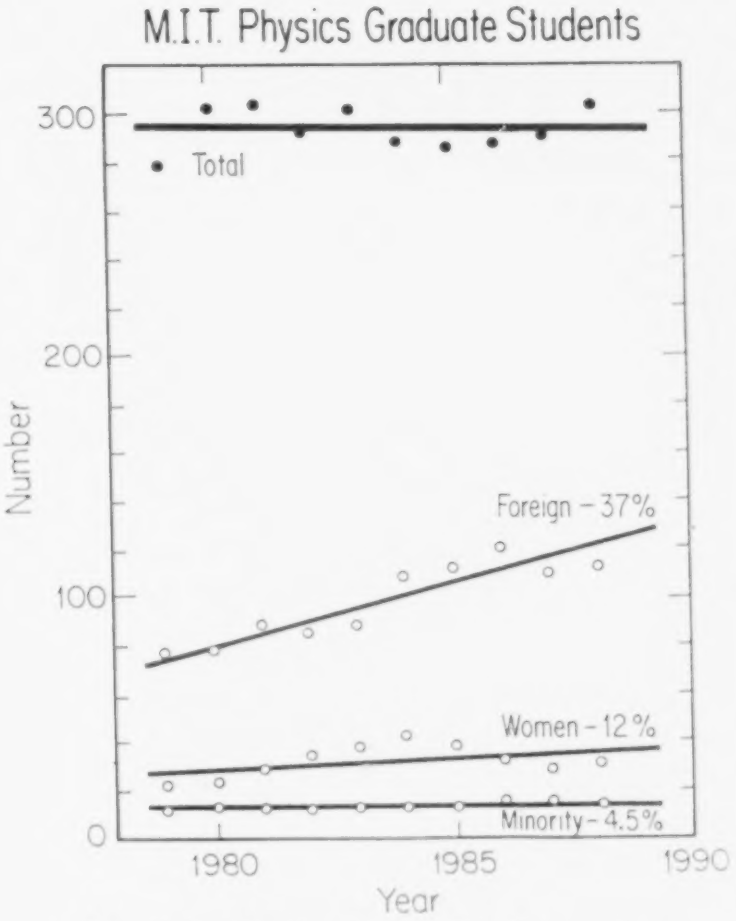

Figure 2. Number of MIT Physics graduate students together with the numbers of foreign, women and underrepresented minority students for the past decade. More than 90% of these students are in the Ph. D. program. The percentages shown in the figure correspond to the 1988-89 academic year.

to have larger groups. Second, in addition to the faculty, the department has associated with it 13 senior research scientists, 12 of whom are experimentalists. A number of these senior research scientists also supervise physics graduate students. Barring some completely unforeseen event, we do not anticipate any drastic change in the total number of Ph. D. candidates in the next decade.

We also show in Fig. 2 statistics for women and underrepresented minority Physics Ph. D. students. Within normal statistical fluctuations, the number of women graduate students is either constant or possibly increasing slightly. Women constitute about 12% of our graduate students compared with the national average of 9%. Again this difference is probably not statistically significant. MIT does, however, stand out in the number of women Physics faculty: 1 Dean, 1 Institute Professor, 2 Full Professors and 2 Assistant Professors. Further, especially in recent hiring, there have been many excellent women faculty candidates. Thus we are optimistic about the future participation of women in Physics.

The situation for underrepresented minorities (Black, Hispanic and American Indian) is less positive. The percentage of minority Physics graduate students at MIT has been approximately constant at ~4.5% for the last decade. This translates into approximately one Black and one Hispanic Physics Ph.D. per year. Of course, by any absolute standards this would appear to be quite dismal. However, it turns out that we are much more successful at MIT in educating minorities than our sister institutions. The national average for underrepresented minority Ph.D.'s in Physics is closer to 1.5%. Our relative success in this area involves several factors. First, the Institute has provided several graduate fellowships which are specifically earmarked for minority graduate students. Second, one of our faculty serves as Minority Graduate Officer; he keeps careful track of the progress of the minority students and often functions as an ombudsman. Third, our own minority Physics Ph.D. graduates act as ambassadors for us by sending to MIT their best minority undergraduate students.

Unfortunately, there does not seem to be an immediate prospect for a drastic increase in the number of minority Ph.D.'s in Physics. The underlying causes for the paucity of minorities in science have been treated extensively in many studies. The issues are complex and certainly cannot be solved by a research-oriented graduate Physics program. As noted above, the indicators for the near future are not very positive. For

example, at MIT nearly 15% of our undergraduates are Black or Hispanic; however, very few of these students are choosing to major in Physics.

The final data shown in Fig. 2 are the numbers of foreign national graduate students. Our MIT statistics are essentially identical to the corresponding national averages. In brief, the percentage of foreign nationals is gradually increasing; this is in spite of the fact that the admissions process appears to be biased towards students who were undergraduates in the United States. It seems quite likely that this trend will continue, with the percentage reaching 50% by the year 2000. There are two possible reactions to this trend - the first is the jingoistic assertion that U.S. citizens should be given extreme preference. Alternatively, one can take the view that foreign nationals represent an

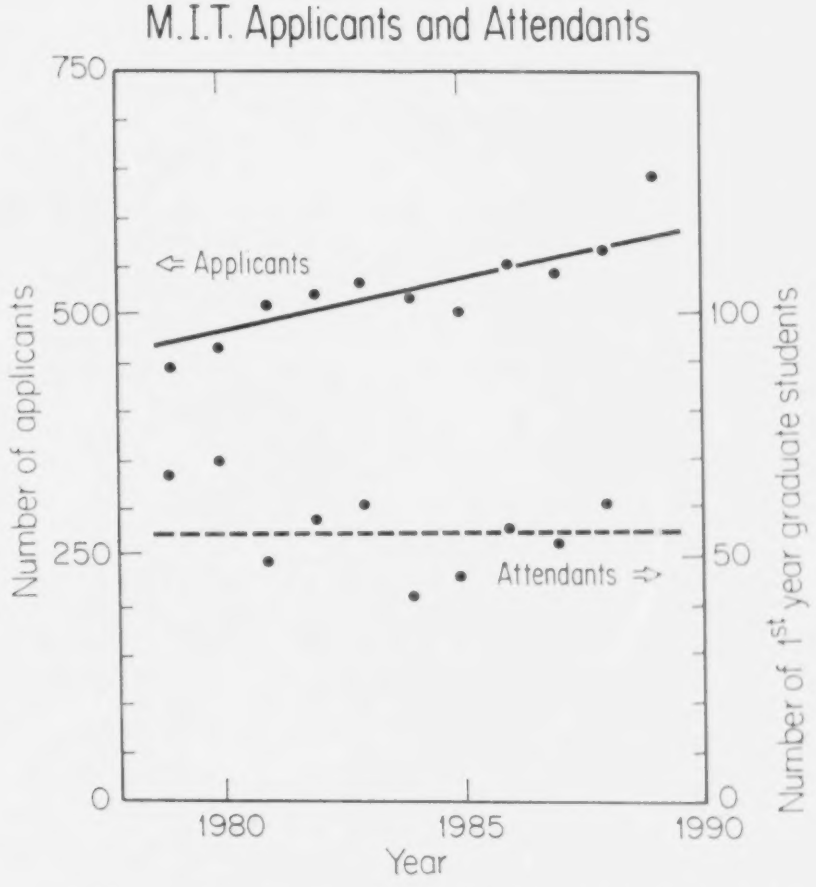

Figure 3. Number of applicants and number of 1st year graduate students in the Physics Department graduate program at MIT.

important resource for the U.S. and that we should take as much advantage as possible of this pool of talent. Of course, at MIT, we favor the latter approach. Indeed more generally, it is clear that in the next decade the U.S. economy will depend more and more strongly on the availability of large numbers of foreign scientists and technologists. Hopefully, the Department of Immigration and Naturalization will soon start to aid rather than hinder this process.

One feature of graduate education at MIT which is unusual is the relatively small number of students employed as teaching assistants (TA). Specifically, among ~290 Physics graduate students, ~35 hold teaching assistantships, ~200 are research assistants and most of the remaining hold MIT or external fellowships. The reason for the small number of TA's is that in our department recitation sections are primarily taught by faculty. We do not anticipate any significant change in these numbers in the near future.

Finally, we show in Fig. 3 the number of applicants and the number of actual first year graduate students for this past decade. The number of applicants has been increasing progressively each year reaching a maximum of ~650 in 1989. On the other hand, the number of entering Ph.D. students has been approximately constant at 55. As discussed previously, the latter number is controlled by the size of the faculty and the available resources.

III. Research Preferences

As we noted at the beginning of the article, our department has strong research programs in most major branches of Physics. Thus our applicants' expression of preference of research areas should reflect properly the opinions of the general physics student population. The statistics for the MIT 1989 Ph.D. applicant pool are shown in Fig. 4. It is clear that two areas stand out well above the rest: elementary particle theory and condensed matter experiment. The next grouping, with a factor of ~ two fewer candidates, includes atomic physics, condensed matter theory and elementary particle experiment. Somewhat surprising, especially for MIT, is the very small number of students who choose nuclear physics as their first preference.

One figure of merit for ranking the applicants is the student's score on the Physics Graduate Record Exam. This turns out to be quite uniform across the different research areas. Specifically, our average applicant is at the 70th percentile whether he/she wants to

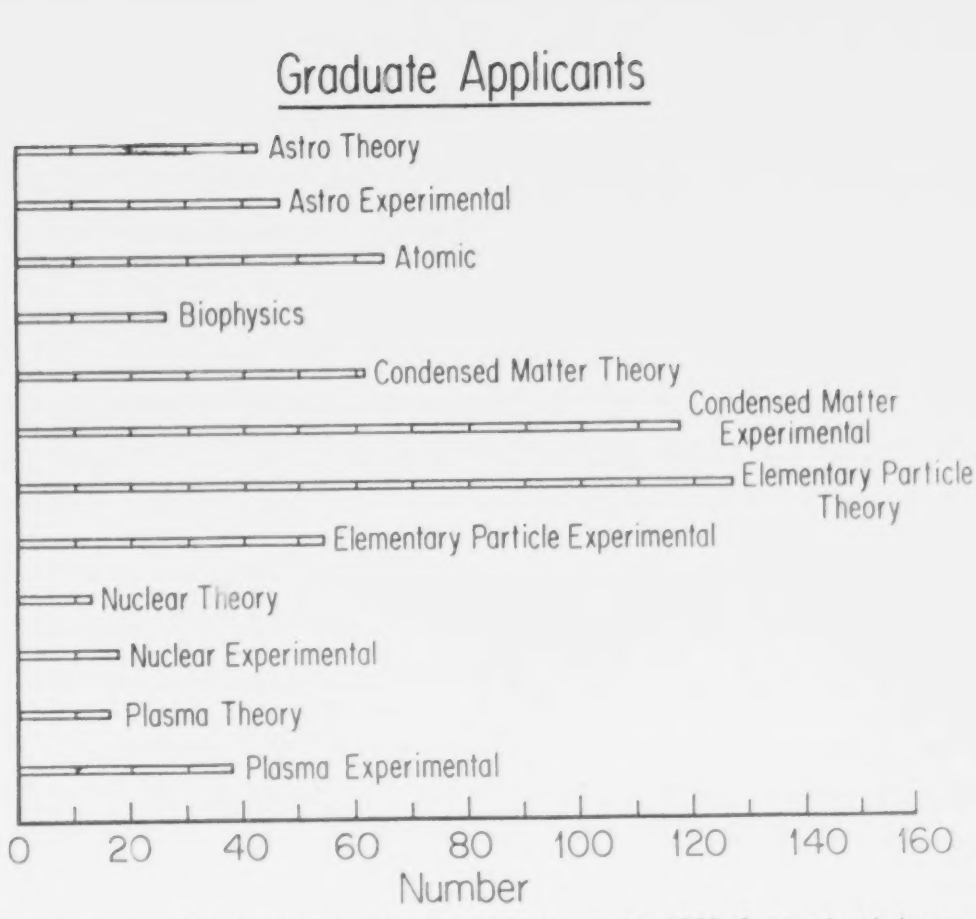

Figure 4. Number of graduate applicants in 1989 factorized into the research areas which they have specified as their first preference.

pursue a Ph.D. in, for example, elementary particle theory or astrophysics experiment. The ranking of the students who actually come to MIT is, however, much more varied. This clearly depends on the availability of support in particular areas (at MIT the majority of our entering graduate students are supported by research assistantships in specific research areas) and on the current reputation of the faculty. At MIT, the best students are in condensed matter theory (92nd percentile) followed by condensed matter experiment, elementary particle theory and atomic physics (all ~87th percentile).

What research areas do the students actually end up pursuing? The distribution for the 1988-89 academic year is shown in Fig. 5. As is evident from the figure, by far the largest number is in condensed matter experiment. This is particularly notable since our department has only 8 condensed matter experimentalists on the faculty. Indeed, there are many more students carrying out thesis research in this area than were admitted by the condensed matter group. Many of these students are actually supervised by faculty in other

departments such as Materials Science or Electrical Engineering. Accordingly, their Physics graduate education has a strong engineering flavor and indeed most of these students go on to careers in applied physics or engineering. As is evident from the figures, the numbers of graduate students in other areas of Physics are comparable. One notable feature is that, percentage-wise, the number of students carrying out thesis research in elementary paricle theory is much less than the number of applicants. This is due primarily to the very limited number of research assistantships available in this area.

For the past twenty years, quite precisely 25% of physics graduate students nationally have done Ph. D.s in condensed matter physics. In our department this number is currently 30%; it would, however, increase significantly if the condensed matter faculty were increased beyond their current level of 15% of the total faculty.

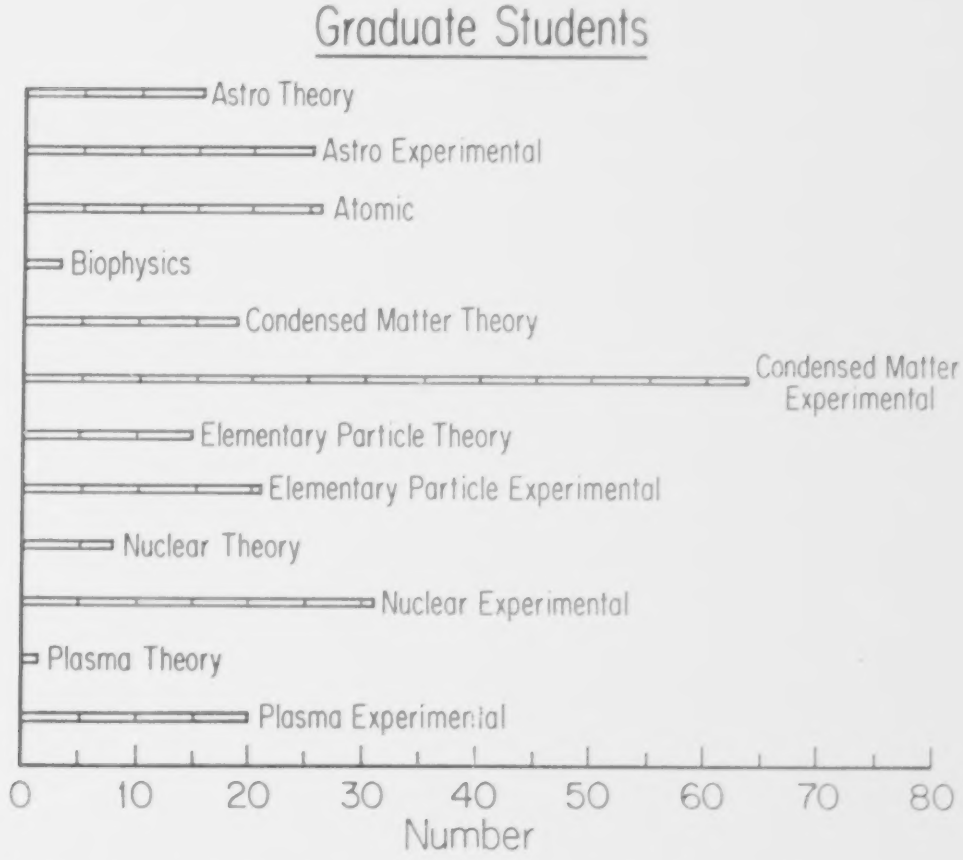

Figure 5. Numbers of Physics graduate students in various areas of Physics in the Department of Physics at MIT.

IV. Issues for the 90's

There are many important issues which are of direct concern for the overall health of our department, for graduate Physics education at MIT, and, we believe, for Physics as a whole in the United States. Here we would like to discuss a few of these issues. Unfortunately, we will present here mostly problems rather than solutions.

As we discussed previously, for complicated sociological reasons, certain minority groups barely participate in the Physics enterprise. This is, of course, an enormous waste of talent. As we enter the 21st century it will be more and more important for the health of U. S. science and technology that this talent pool be accessed. As we discussed in Section II, at MIT we educate nearly three times the national average of underrepresented minority Physics Ph. D.'s. One important reason for our long-term relative success in this area is the minority graduate fellowships provided by MIT.

The National Science Foundation has a genuine commitment to minority education. However, their programs are not as effective as one would like. One clear lesson from our MIT experience is the importance of department-controlled dedicated fellowships. We suggest therefore that the National Science Foundation fund directly three graduate fellowships for underrepresented minorities at all leading research Universities which are willing to make a commitment in this area. We are confident that this will have a measurable impact on the number of minorities in our Physics graduate schools.

Women are, of course, also severely underrepresented in Physics. Fortunately, however, the percentage of Physics Ph. D.'s nationally who are women has more than doubled in the last decade. The percentage increase at MIT has been less but then our fractional participation was much larger to begin with. This is undoubtedly due to the large number of excellent women on our faculty. We are therefore sanguine that women will become an increasingly important part of the Physics community in the United States. We would like to add one subjective observation to the objective statistics. It is our impression generally at MIT that not only is the number of women in Physics increasing but the female candidates for junior faculty positions seem much more secure and comfortable in their roles as physicists. Thus real progress has been made on this front.

It is clear, from Figure 2 and from the corresponding national figures that the United States will be increasingly dependent on foreign national physicists in the 1990's.

Of course, since the United States is historically a country of immigrants this is not a new or unique phenomenon. Obviously, one would like to persuade more American citizens to seek advanced education in Physics and the other hard sciences. Nevertheless, this growing pool of foreign national physicists should be viewed as an opportunity rather than a problem. Currently, the most serious difficulty connected with foreign nationals seems to be the bureaucratic impediments imposed by the Department of Immigration and Naturalization. It is essential for the future of science and technology in the United States that the immigration process for foreign Ph. D.'s be made as straightforward as possible - that is, the government should be aiding rather than obstructing the hiring of highly educated foreign national scientists by our universities and industries.

We would now like to discuss two rather different issues which impact directly and indirectly graduate Physics education. The first issue is the trend in Physics towards larger and larger scale experiments. The most extreme examples of this evolution are in elementary particle physics where collaborations may involve more than 400 physicists. It is very difficult for any junior faculty physicist to emerge with a clear identity in such a collaboration. It is even more difficult to define a graduate student thesis project which is self-contained and which involves some clear physics accomplishments actually produced by the student. Large scale projects are also becoming much more common in nuclear physics, plasma physics and even in condensed matter physics.

One solution would be simply to concede all large experiments to the national laboratories. However, it is our view that this would be a serious mistake for many reasons. First, in the United States the most talented physicists are generally at universities and our advanced research projects should be carried out by the best scientists. Second, it is the obligation of physicists at our leading research universities to pursue research at its frontiers. If this requires large collaborations then we must learn to adapt our structures to this requirement. Third, it is our view that there is no better graduate education than participation in the most important and exciting research possible. Fourth, for the health of these fields there must be a continuing supply of talented, enthusiastic young physicists. This can only come through our graduate schools.

There are, as noted above, also significant problems for junior faculty participating in large experiments. How, for example, does a young elementary particle or nuclear experimentalist achieve enough visibility to gain the international recognition required to meet our tenure criteria? Further, how does this person establish herself as a committed

and successful teacher and supervisor of graduate students when she must spend a substantial fraction of her time at the experimental site? These are problems which we are currently struggling with but we have no clear answers. We would welcome input from other departments which are addressing these issues.

The final problem which we would like to mention, again without a clear resolution, is that of retirement. Perhaps the most charming aspect of our profession is that physicists love their work and are typically quite reluctant to retire. Thus, compulsory retirement at some fixed age has played the invaluable role of guaranteeing openings for young physicists and has allowed one to terminate some less productive faculty members with grace. Beginning in 1994, compulsory retirement by age will be illegal in the United States in academia. We do not believe that our department can tolerate this indefinitely. One possible solution is to grant tenure for a fixed length of time, say 30 years, and then to have a biannual review of performance. However, this would undoubtedly create some extremely unpleasant situations in our department - how do you tell a capable but declining physicist that he/she is no longer functioning at an acceptable level? What criteria would one use?

At this stage, university upper Administrations are reluctant to address this issue. This is, in part, because they perceive that it will only be a serious problem in a few departments, with Physics being the most prominent of these. In most other fields, the vast majority of the faculty apparently are more than happy to retire well before age 70. Again, we are struggling with this issue in our department at MIT and we would welcome input from other institutions.

There are, of course, many other issues which concern us: undergraduate and graduate curricula, soft versus hard money academic year salary support, relationships with industry, graduate student fellowship support and research funding for junior faculty among others. Hopefully these issues will be addressed in other articles in this volume.

Acknowledgements

I would like to thank Douglas Fitchen for inviting me to give this talk. It provided an excellent stimulus for me to take stock of our current situation at MIT. I would also like to thank Catherine Ormond, Daniel Kleppner and George Koster for assistance in gathering the data shown here and for invaluable discussions.

VIEWS FROM A SMALLER DEPARTMENT

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Discussions at the national level about graduate education and research in physics often focus upon or represent the "top" or "larger" departments. However, there are some 800 institutions which offer bachelor's degrees in physics or related areas, and some 170 of these offer Ph.D.'s. The following are a potpourri of comments from a "smaller" department.

The Student Pipeline Problem

All who educate or employ physicists are seriously concerned about their future supply. An oft discussed question is, "How do we get more students through the pipeline?". The simple answer is, "more foreign-born, and plug the leaks along the entire length of the pipeline." A few observations follow.

In K through 6th grades students begin to develop an uneasy feeling about science. Elementary teachers, with notable exceptions, avoided science themselves. Students sense their teachers' fears of science; the more effective these teachers are as role models, women in particular, the more disastrous the image of science which builds up in the students' minds. In addition, the electronic media, an equally important source of image building, portrays the physicist as wicked or weird or both.

Things do not improve in 7th through 12th grades, where many teachers of physics are poorly prepared and raging hormones dominate student thought processes. Students satisfy their science requirement avoiding physics--it's hard--only weirdos take physics--don't ruin your GPA or you won't get into college X. Counselors are confused by the differences between physics and engineering and advise students good with their hands to go into engineering (besides, parents like offspring to have high paying jobs), and those good with theory (math?) to think about physics, even though it is "useless" as a career option. Electronic and print media continue to cast the physicist in the same wicked or weird mode, with the engineer the contributor to new and better consumer products. Due to the lack of public understanding of physics, parents, as well as counselors, in general are not supporters of a physics career, particularly for women and minorities.

In spite of all this, a few get into our bachelors programs, some adroitly stolen from engineering. A few hours of experimental physics are slipped in with a heavy load of math and theory courses--which, of course, is fine with many of the students with those leanings in the first place. Majors are reminded frequently by fellow students, parents, the career placement bureau, and lack of recruiting visits in physics that jobs for bachelors in physics are in engineering-type jobs. Otherwise, it's graduate school. Countervailing arguments of breadth, outmobility and intellectual excitement, as well as a support system for those who go on for graduate work plug some leaks for white males. However, they are largely ineffective for most females and minorities, where a much better support system must be instituted.

The British Institute of Physics recently did a study to determine why students go into physics. They found they were attracted by gravity, astrophysics, and particle theory, not inconsistent with the U.S. students with a heavy math-theory interest. The shock comes later, when they realize that career opportunities are more abundant in experimental condensed matter, atomic, molecular, and optical physics.

Thus, by the time students are recruited for graduate school an outmigration of many experimentally oriented students has taken place at various levels, including the job opportunities at the bachelor's level. In addition, support systems and role models developed historically for white males, so females and minorities are too frequently discouraged or already gone; recent strong efforts to change have yet to bear lasting fruit. Those few women and minorities who enter graduate school in physics have high drop out rates since they respond differently to pressure and have a different image of themselves (See article by Sheila Widnall, Science, 9/30/88).

Approximately one-third of the students who begin graduate school in physics obtain a Ph.D. It is in our hands to change this fraction by a slight change in the standards which are all too often set to clone university research faculty. Given the nature of many of the jobs "requiring" Ph.D.'s, but not in research universities, a modification of standards may be acceptable and worthwhile--these positions will be filled by someone! Recognizing this cloning process some students either drop out, stop at an M.S., or outmigrate after a Ph.D. In addition, they see the time to get a Ph.D. increasing (an increase of one year in the last 20).

Educating and Recruiting New Faculty

In thinking about graduate education for the 90's it is appropriate to give some consideration to the needs and desires of potential employers. Prospective faculty need to understand the various career opportunities available and how to make the best choice for their long range interests. New faculty in Ph.D. granting departments must choose good research topics, write competitive proposals, and know when and where to send them. Graduate programs provide little of this type of experience. Writing skills are not honed and dissertations are becoming stapled published papers, often written in part by co-authors.

New faculty need to be good teachers and advisors. Where in the graduate curriculum do students have apprenticeships to learn these skills? Some may wet their little toes as teaching assistants, but certainly that is not the level of experience required for a faculty position.

New faculty need to understand "the profession" including the issues surrounding integrity, racism, sexism, and plagiarism, as well as knowledge of the structure of academic institutions and federal agencies. These are particularly important issues for our foreign-born Ph.D.'s due to cultural differences, but they are largely ignored during the Ph.D. program. The "cold fusion" story provides an excellent format in which to discuss professional ethics.

Departments offering only the B.S. degree generally prefer experimentalists in condensed matter, atomic, molecular, or optical physics. The demand for these subfields in all areas of employment, coupled with low salaries, heavy teaching loads, and difficulty arranging start-up funds makes it extremely difficult for these departments to hire in these areas. It is likely that many of these positions will be filled by theorists, and the nature of the undergraduate education could change to even more concentration on theory. This indicates the need in the graduate curriculum for a required component of experimental physics, so that even theorists have basic laboratory skills to share with undergraduates.

At Ph.D. granting institutions, although the salaries are better and classroom teaching loads lighter, hiring in these same experimental areas is difficult. These difficulties revolve around the large start-up budget required. There is the attendant possibility of an evolution toward more theory as the competition continues to mount.

Top graduates continue to migrate to industrial and government labs, which seem more able to solve the start-up problem and, in addition, generally have

higher salaries and sustained funding. Industry and government labs must give serious consideration to the possibility that they are eating the country's "seed corn" in some areas. In ten to 15 years, the universities may be unable to provide physicists with experience of interest to industry.

Another concern revolves around the large user facilities and centers where students spend a majority of their graduate student life. Their educational experiences are certainly different from their peers' who remain on campus. In addition, serious family dislocations and problems arise with spouse separation. Single spouse families have arisen where one spouse spends a substantial fraction of time in another community. Some students are avoiding those fields where this lifestyle dominates.

Additional Thoughts

1) Some paranoia arises from comments made by representatives of large departments that it is a waste of government and state resources to support the smaller programs. Smaller departments are constantly fighting that particular attitude. It is divisive, unnecessary, and based on erroneous thinking.

2) Smaller departments expect to compete, but they ask that the rules be fair and not prejudiced. On occasion changes or trends or new programs at federal agencies mitigate against the smaller departments. There seems to have developed the feeling that if money is spent on large projects rather than on P.I.'s in smaller projects that the research is somehow more cost effective and improved. History has shown that larger institutions do not have a corner on creative and break-through ideas. In addition, over the past 20 years it is the smaller schools which have been hiring many of the best Ph.D.'s from the larger schools. Therefore, a significant amount of the nation's physics talent now resides in the smaller institutions.

3) Smaller institutions are a source of graduate students to the larger institutions. In many cases the smaller institutions spend more effort on the undergraduate student education and produce excellent students.

4) Ph.D. students from smaller institutions have no difficulty in finding positions and many fill jobs in smaller industries and smaller teaching institutions as well as in government laboratories. They play a very productive role, particularly regionally.

5) Smaller departments have accepted the regional challenges of educating the general public about science and have easy relationships with grades K through 12. They seem more ready to admit that a legitimate activity of a faculty member is to be creative in educational areas other than research. This is due in part to the fact that they focus on a small number of areas and on finding niches in which to develop excellence, not attempting to cover all areas of physics. There is often some flexibility left over or built in to focus on other nontraditional creative activities. In addition, the administrations may be more friendly towards these activities.

6) A growing problem for all departments, but particularly the smaller departments, is the requirement of spouse employment in the same institution or community.

7) The most important argument for the existence of active, smaller Ph.D. granting departments is the impact that department has locally, both on the quality of education and on the ability of the region to attract industry and business. As is well known, a major fraction of the new jobs created in the United States are the result of new and smaller companies coming into existence. These companies are sprouting all over the country, in particular around university communities.

Conclusion

It is in the best interest of the country as well as the larger departments to have smaller departments of quality spread around the country for many reasons, some of which were discussed here. Smaller departments should have a greater role in shaping policies and programs in the country.

Terence L. Porter
Division Director
Research Career Development
National Science Foundation

Issue: Support for entering graduate students

Topic: Nationally-competitive graduate fellowship programs, with particular reference to the NSF graduate research fellowship programs.

A. Fig. 1 lists the principal nationally-competitive graduate fellowship programs open to young physicists. Even though there has been some increase in support in recent years, clearly NSF remains the major source of support of this kind.

B. Fig. 2 shows some statistics of the NSF graduate fellowship program over the past five years. In this period the stipend associated with these fellowships has stayed level, except for about a 10% increase in 1987 to maintain a level take-home stipend in the wake of the 1986 Tax Reform Act. Note that the success rate (awards/applications) for physicists is consistently somewhat greater than for the competition as a whole. A few years ago we instituted a small cross-discipline review procedure designed to assure that attention is paid to equalizing the merit of awardees across fields, and physicists have benefitted from this action.

C. These figures do not include data for the NSF Minority Graduate Fellowships, a component of graduate research fellowships that was initiated in 1978. A few additional awards are made annually to physicists in this component.

D. Where do we go from here?

1. As might be suspected from Fig. 2, NSF Fellowships are in a growth period. The total number will about double over 1987-1991. These increases will be disproportionate in favor of the minority graduate component. A third component, graduate fellowships for women in engineering, will be inaugurated in 1990 at which time an additional 80 awards, divided among the graduate and minority graduate components, will be made to female engineering applicants. The cost of this new initiative will be shared with NSF's Directorate for Engineering. Some stipend increases may also be expected.

2. NSF's research directorates in the last two years have been able to offer some additional graduate student support to minority graduate fellowship honorable mentions. This trend may be expected to continue.

3. The Program continues to be concerned that too many potentially outstanding graduate students are slipping through our publicity net, especially, but not limited to, minorities and women. Additional efforts are planned to disseminate information about graduate study in general and NSF fellowships in particular.

4. We continue to regard NSF graduate fellowships as essential to guarantee to our Nation at least a minimum presence of outstanding research scientists and engineers in the decades to come. We attach the highest priority to maintaining the portability of these fellowships and the assignment of awards to the most outstanding applicants regardless of field.

Fig. 1

SELECTED GRADUATE FELLOWSHIP PROGRAMS

WITH NATIONAL COMPETITIONS

1989

	YEAR STARTED	NEW AWARDS	NEW PHYSICS AWARDS
NSF	1952	760	75
HERTZ FND.	1963	30	7
OFF. OF NAVAL RESEARCH	1982	50	6
AIR FORCE OSR	1986	25	5
NAT. DEF. GRAD. FELLOWSHIP (DOD)	1989	124	11

Fig. 2

NATIONAL SCIENCE FOUNDATION

GRADUATE FELLOWSHIP PROGRAM APPLICATIONS AND AWARDS

	------ALL FIELDS------		-PHYSICS & ASTRONOMY-	
	APPLICATIONS	AWARDS	APPLICATIONS	AWARDS
1985	4,390	540	353	45
1986	4,879	505	352	40
1987	4,726	505	308	37
1988	5,151	685	380	59
1989	5,367	760	445	75

Human Resource Concerns at NSF

Kent Wilson
National Science Foundation

Within the topic of graduate education in physics, I wish to focus on the availability of human resources. In my view, this problem outweighs all other concerns about the research enterprise – no people, no research.

Historically in the United States, we have funded science by first- and second-generation immigrants. The ethnic mix has continually changed, but as Third-World countries develop, where can we turn? We must be able to rely on homegrown talent.

In the near future, white males will make up only 15 percent of the incoming work force, and births to black and Hispanic mothers will predominate. These ethnic groups at present show little interest in pursuing science as a profession. As a matter of national interest (quite apart from equity considerations) we must make science careers attractive to members of these minorities. We have been throwing dollars at this problem but with little demonstrable success.

Another large, but relatively untapped, resource of scientists is women. The problems associated with producing female and minority scientists are different. Women enter the science pipeline but leave. Minorities do not enter the pipeline.

Whatever the solutions to these problems are, they probably are different for the two groups. However, it is my judgment that serious, massive mentoring activities must be at the heart of any successful program. We can all point to a particularly caring individual (teacher, relative, friend) who was pivotal in our choice of science as a career and to our success. Mentoring is relatively inexpensive in terms of dollars but expensive in terms of time and, most importantly, commitment.

Obviously, the human resource problem must be attacked all along the pipeline from grade school to graduate faculty. Since the research directorates at NSF are primarily concerned with graduate and undergraduate education, I will describe some of the efforts that the Mathematical and Physical Sciences Directorate is currently undertaking. There is increased emphasis on undergraduate education. We have committed $12 million in FY 1989, will increase this to $20 million in FY 1990, and anticipate greater increases in FY 1991 and beyond.

The Research Experiences for Undergraduates program will expand with increased emphasis on serious mentoring and concern for minorities and women. Similar concerns are involved in decisions on research grant applications. Special programs for special groups always raise the question of stigma. No one wishes to feel that his or her success came as the result of special bias in the review process. At NSF, compromising quality is not an issue, as the quality cutoff for awards is so high that secondary criteria can be used without fear of supporting poorer research. I anticipate that education and pipeline issues (quality of teaching, mentoring efforts with women and minorities, etc.) will become more important in the review process.

To be effective in this process, the outlook of the NSF program staff must be broadened. It is no longer sufficient for a program director to be expert in a discipline or subdiscipline. An effective program manager must also be aware of and concerned about this pipeline issue. As I said before, if we do not have people to twist the knobs (or punch the keyboards) it will make no difference what facilities are available.

Program Balance within the NSF Physics Programs

Thomas Applequist
Yale University

Reporting for the Advisory Committee for Physics (ACP), Thomas Applequist presented the general conclusions of the first stage of a review conducted by the ACP. He also provided detailed tables showing turnover and trends in NSF funding of programs in physics (Tables I and II).

General Conclusions

1. There is a severe funding crisis throughout the Physics Division: very small grant size, very small percentage of new proposals funded, very high percentage of renewals declined, and many good ideas don't reach the proposal stage.

2. Extreme stress in condensed matter theory exists.

Recommendation One

The funding crisis in the core of our nation's basic physics programs is real and must be addressed. Without significant increases in basic research funding, we will not be able to fill our scientific pipeline with outstanding people, nor effectively utilize our talented senior scientists to stabilize our technological future. We specifically recommend that restoring adequate support for these core programs be given highest priority within the NSF and that initiatives such as additional Science and Technology Centers not be funded until these problems have been resolved.

Recommendation Two

Across the board, set-up funds are becoming the limiting step in the ability of the nation to attract to university careers the outstanding faculty needed for our future. We propose the establishment of a matching grant program (50% university and 50% NSF) for new experimental and theoretical faculty research equipment. To be effective, this program must be funded at a significant level and reach young faculty rapidly (at the beginning of their academic careers).

Recommendation Three

We recommend that an in-depth review of the AMO program occur during the next year by a cross-disciplinary review team to evaluate the present and future national needs in this area of research and education, and to define the appropriate funding strategy.

Recommendation Four

An *incremental* increase (beyond inflationary adjustments planned for FY 90) of $2 million (as was recommended in the MacDonald Report) should occur over the next two years in the theory program. These incremental funds should be used primarily to increase the support levels of individual grants, with a particular emphasis on providing equitable support of graduate students and postdoctoral fellows. Special effort should be made to increase support levels in AMO and nuclear theory. Annual guidelines should be established by the theory program managers for the subprograms in EPP, AMO, and nuclear theory.

Recommendation Five

The subcommittee recommends that the Physics Division adopt a specific uniform pattern of record keeping across the Division and that this provide the basis for detecting historical manpower and funding trends.

Summary

1. Severe funding problems throughout the Physics Division and in Condensed Matter Theory.
2. Much concern over the impact of big initiatives.
3. New review process by the Advisory Committee for Physics.
4. Successful first pass by the ACP. Excellent cooperation from the Physics Division staff.

TABLE I

Funding and Turnover by Program

	FY 88	FY 85-88 % turnover per year[1]		FY 87 $ per Senior Personnel[2]	
	Total	Senior Personnel	Dollars	Theory	Expt
Physics					
AMO (+ plasma)	$13.3M	7%	8%	$36K	$122K
EPP	$22.8M non-facility; ($41.7M) total	8% (FY 87 only)	6.1% (FY 87 only)	$61K	$142K (w/o CESR)
Gravitation	$8.9M	14% (expt) 7% (theory)	6% (expt) 4% (theory)	$53K	$121K
IENP	$9.6M non-facility; ($17.8M) total	5%	5%	} $46K	$85K[3] (w/o Univ labs)
Nuclear	$13.4M non-facility; ($21.0) total	6.5%	6.5%	}	$78K[3] (w/o Univ labs)
Theory	$15.2M	8%	3-4%	See above	
Materials Research					
Condensed Matter Theory	$8.8M	10-11%	10-11%	$59K	

[1] Assuming typical three-year grant cycles, an annual turnover of 11% would correspond to denying one-third of the renewals.

[2] Support in DOE for individual senior personnel is typically 30-40% higher.

[3] Support for large scale University facilities in IENP & Nuclear Physics appears to be roughly similar between NSF and DOE (after correcting for public vs. private overhead rates).

Table II

Trends in NSF Funding (in Millions)

	FY85 Actual	FY88 Actual	FY89 Current Plan	FY89[1] FY85	FY90 Requested	FY90[2] FY89
NSF Total	1502.0	1723.0	1885.0	25.5%	2149.0	14.0%
NSF Res + Related	1301.0	1453.0	1583.0	21.7%	1803.0	13.9%
MPS	397.2	472.0	503.3	26.7%	553.5	10.0%
DMR	107.0	110.6	115.0	7.5%	135.2[3]	17.6%
PHY	115.8	117.9	122.6	5.9%	130.0	6.0%
AMO	13.60	13.30	13.5	-0.7%	14.4	6.7%
EPP	39.78	41.73	41.0	3.1%	43.4	5.9%
Gravition	7.21	8.92	9.8	35.9%	10.4	6.1%
IENP	18.34	17.82	19.7	7.4%	20.8	5.6%
Nuclear	22.99	20.96	22.7	-1.3%	23.9	5.3%
Theory	13.87	15.18	15.9	14.6%	17.1	7.5%

[1] Percentage change FY89 relative to FY85

[2] Percentage change FY90 relative to FY89

[3] This increase includes $12 M for initiation of a 4-year program to build a high magnetic fields facility at a total price tage of $100 M to serve DMR and the chemistry and biology community. If this facility addition is separated from the budget, then the DMR FY90 requested figure is $123.2, an increase of $8.2 M (7.1%) for the "normal" programs.

CONDENSED MATTER PHYSICS IN THE 1990'S

Judy R. Franz
West Virginia University
Division of Materials Research Advisory Committee

I've been asked to speak about condensed matter physics in the 1990's. Although condensed matter physicists are supposed to have special insight into crystals, I'm not sure this carries over to crystal balls, but I shall do my best. As we approach the 1990's, the field of condensed matter physics is experiencing a period of high excitement and very rapid growth. Dramatic new discoveries are being announced with increasing rapidity and the job market is strong. One might reasonably expect this situation to continue well into the next decade. There are some storm clouds on the horizon, however, which are the result of the woefully inadequate funding available to researchers in this field.

I want to start by showing you a number of indications of the vitality of condensed matter physics. I'll then spend a little time talking about the funding situation as viewed by someone outside the funding agencies. Finally, I'll try to project the current situation somewhat into the future and raise some questions that perhaps can be discussed more fully later in this conference.

To indicate the current excitement in the condensed matter physics, I'll list just a few of the recent areas of development within the field:

High temperature superconductivity
Disordered and artificially structured materials
Scanning tunnelling microscopy
Femtosecond spectroscopy
Quantum well phenomena
Lower dimensional magnetism
Nonlinear phenomena and chaos
Noise and fluctuations in microelectronic devices
Growth and nucleation in self-organizing systems
Biomaterials

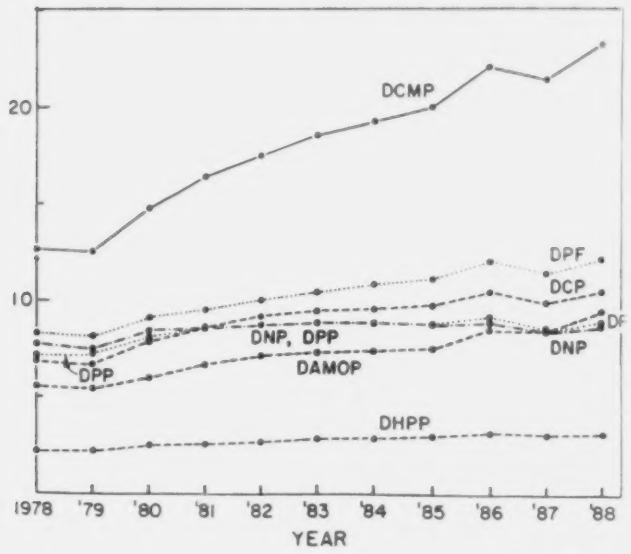
As a result of the outpouring of new and exciting research, large numbers of students and scientists in neighboring areas such as chemistry and materials science have been joining with condensed matter physicists in tackling many of the current problems. This increasing interdisciplinarity of the field has added to its dynamism.

Although excitement is hard to quantify, growth is measurable. I want to show you some data that document the recent growth in the field of condensed matter physics and seem to indicate that this growth will continue for some time. Several of these data highlight condensed matter theory rather than the field as a whole. This is only because I had this information readily available in a report that Neil Ashcroft and I recently wrote on The Growth of Condensed Matter and Material Theory.

In the figure below, the APS divisional membership is shown as a percentage of the total APS membership for the last ten years. The very rapid growth in the Division of Condensed Matter Physics (DCMP) is evident. The membership of DCMP

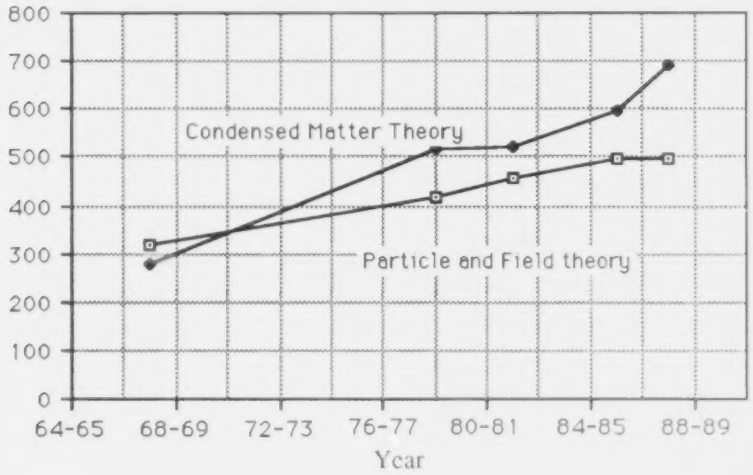
has grown from 3803 in 1978 to 9254 in 1988. This increase of 5451 members is larger than the total membership of any other division.

APS Divisional Membership (% of Total APS Membership)



The next figure shows, for a 21 year period, the number of faculty in condensed matter theory at universities with graduate programs in physics. Also shown, for comparison purposes, is the number of faculty in particle and field theory, the next largest area. Data for this graph were compiled from five volumes of the series, **Graduate Programs in Physics, Astronomy and Related Fields**, produced annually by the American Institute of Physics. The most striking feature of this data is the recent rapid rise in the number of condensed matter theorists, an increase of almost 100 faculty in a two-year period!

Number of Faculty as a Function of Time



This same general trend is observed in a more limited survey of 40 major physics departments that was carried out recently by Dr. Jim Sethna, a faculty member at Cornell University. His survey indicates that the condensed matter theory faculty at the universities polled grew by 28% during the past five years. During the same period, both the high energy theory faculty and the nuclear theory faculty grew by about 8%.

I have less information about the growth of faculty in experimental condensed matter physics, but the same AIP volumes quoted above indicate that there were 937 faculty in this area in 1985-86 and 1001 in 1987-88, an increase of 64. I suspect that the number of experimentalists has grown more slowly than that of theorists because of the very high start-up costs associated with hiring an experimentalist, a factor that I'm sure will be discussed repeatedly during this conference.

The next indication of growth is the number of graduate students specializing in condensed matter physics. In the table below, I show the number of advanced graduate students (3rd year and beyond) in several areas of physics. Averages over three-year periods were used to reduce fluctuations. The data are taken from the annual AIP Report titled **Graduate Student Survey.**

Number of Advanced Graduate Students in Several Areas of Physics

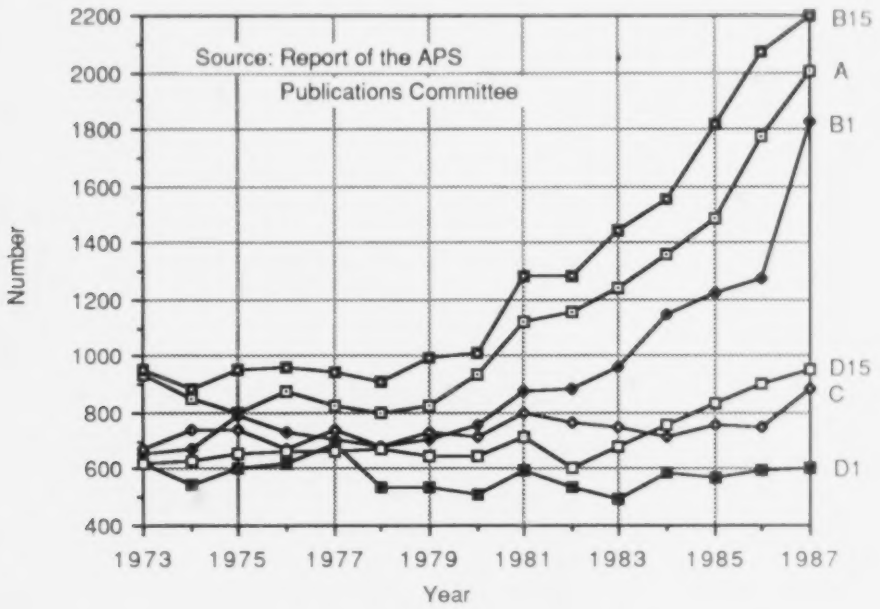
Field	Average # of students/year 1977-80	Average # of students/year 1984-87	% change
Condensed matter theory	344	518	51
Nuclear theory	139	170	22
Elementary particle theory	272	328	21
All theory			**25**
Condensed matter experimental	1073	1784	66
Nuclear experimental	319	413	29
Elementary particle experimental	367	592	61
All experimental			**56**

These data show that during recent years the number of students going into experimental physics has grown more rapidly than the number going into theory. Within the areas of theoretical physics, the increase in graduate students in condensed matter has been twice as large as that in other areas. The influx of students into experimental condensed matter physics has been only slightly greater than into other experimental fields such as particle physics. However, the number of graduate students in condensed matter physics is already so large that we may be witnessing a saturation effect. With the very optimistic estimate that half of the ~ 1000 condensed matter experimentalists have active research programs, each faculty would now need to be able to supervise and support an average ~ 4 graduate students. Many department chairs report that they have more graduate students that want to specialize in condensed matter experimental physics than they can handle. It is, at least in part, this demand that is causing so many departments to seek additional faculty in this area.

Finally, the graph below indicates the very rapid growth in journal publications in the area of condensed matter physics. It can be seen that most of the

increase since 1980 has occurred in Physical Review A and B (115% and 127%, respectively). Physical Review B is, of course, the condensed matter section.

Physical Review Manuscripts Submitted



If the growth in Physical Review A is examined more closely, one finds that most of it has occurred in the areas of plasmas, fluids, statistical physics, and related many body topics. Much of this work is included in the general area of condensed matter physics, at least for funding purposes.

With the field of condensed matter physics growing so rapidly in breadth, people, and productivity, one might expect to find a commensurate growth in funding for this area, but, of course, almost all of you realize this hasn't taken place. The percent increase in NSF support of condensed matter physics over the past four or five years has been quite comparable to that of the rest of physics and **much** less than the pecent increase in the NSF research budget as a whole, as shown below:

Trends in NSF Funding

	% Change Fiscal Year 1985-89
NSF total	25.5%
NSF research	21.7%
Mathematics and physical science	26.7%
Physics	5.9%
Materials Research	7.5%
Solid state physics program	4.6%
Low temperature physics program	9.5%
Condensed matter theory program	13.2%
Instrumentation	-39.0%
Materials research labs plus materials research groups	15.9%

In fact, in constant dollars the the NSF support for research in physics has decreased. The decrease in funds available to NSF program directors for unrestricted individual investigator grants has actually been considerably more drastic than the budget numbers alone would indicate. I'll return to that point in a moment.

What has been the result of a decrease in funds available for a field that is experiencing rapid growth? Most of you know that it has meant that the level of excellence required to get a proposal funded has become intolerably high, so that now well-known physicists with excellent publication records are having their renewal proposals declined. In addition, physicists who have entered the field recently are finding it almost impossible to gain external funding. The PYI program has helped somewhat with this, but if these grants remain open to experienced scientists who move from industry to academia, as they were past this year, this avenue will also effectively be blocked to new assistant professors. In addition, decreasing funding has meant decaying research facilities and outdated instrumentation.

Within the NSF condensed matter sciences section, the program with the greatest proposal pressure has been the theory program. In this program the average grant size of all grants, including the continuing grants, has been cut significantly during each of the last two years. This year's Program Director, David Tong, has reported that in order to fund only 9 out of 89 new proposals received this year, he has been able to fund only 21 out of 42 (50%) anticipated requests for renewal of existing grants. A quick calculation shows that with even a 65% renewal rate for three-year grants, the half-life for funding of those researchers who have been able to obtain grants is only 6 years. Clearly the investment in the education and training of physicists warrants much longer professional careers!

If we look at what has been happening to average grant size, the situation is also bleak. (FY85 stands for fiscal year 1985.)

Average Grant Size in NSF Condensed Matter Physics Programs

	FY85	FY86	FY87	FY88
Condensed matter theory	64K	68K	62K	56K
Solid state physics	80K	85K	81K	81K
Low temperature physics		80K	78K	82K

It is clear that grants of this size are not sufficient to cover the needs of research programs. Particularly in the case of experimental programs, investigators are finding it more and more necessary to seek multiple grants. The amount of time required to write new proposals, renewals, annual reports, etc. is continuing to escalate.

Now I'd like to say a few words about this year's NSF budget request for the Materials Research Division. Information about the Division's budget over the past few years and this year's request are shown below. (Numbers are in millions of dollars.)

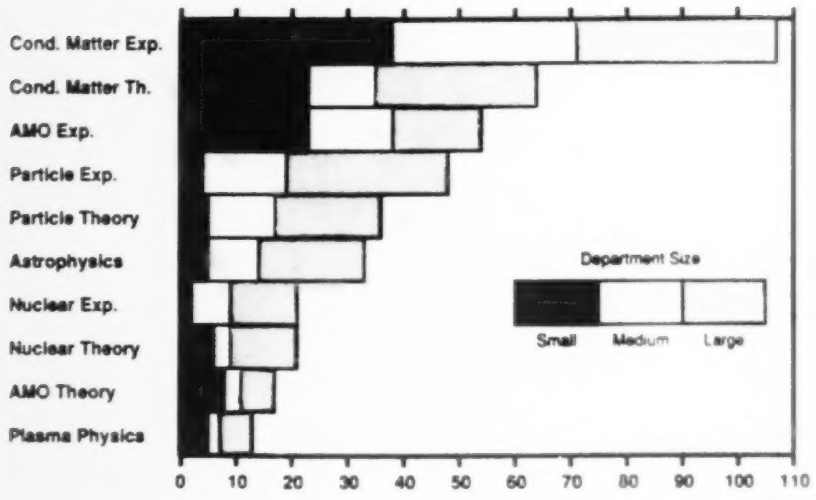
PROGRAM ELEMENT	FY87	FY88	FY89	FY90 Request	90/89 Δ%
Solid State Physics	$ 11.78 M	$ 11.65 M	$ 11.98 M	$ 12.85 M	7.3%
Solid State Chemistry	8.53	8.58	8.81	9.42	6.9%
Low Temperature Physics	7.96	8.22	8.86	9.28	6.9%
Condensed Matter Theory	8.66	8.84	9.34	10.38	11.1%
Metallurgy	9.51	9.03	9.34	9.96	6.6%
Ceramics & Elect. Mat.	6.43	8.14	8.29	9.06	9.3%
Polymers	7.03	7.95	8.16	8.66	6.1%
M.R.L.'s	26.55	26.17	26.19	27.09	3.4%
M.R.G.'s	6.03	7.38	8.07	9.11	12.9%
National Facilities	11.20	10.62	12.13	24.63	
Instrumentation	4.90	3.97	3.99	4.74	18.8%
Total	$108.58 M	$110.56 M	$114.98 M	$135.18 M	17.6%*
SCIENCE & TECH. CENTERS	-	-	$ 10.22 M	?	

*Without high magnetic field laboratory: 7.1%

This year's request for the Division of Materials Research is 17.6% above last year's budget. It is important to note, however, that this includes $12 M for capital equipment for a new high-field magnet laboratory. The requested increase without the funds for the magnet lab is 7.1%. The numbers in this table also include funds for cross-directorate programs such as undergraduate education. These funds are not available for unrestricted individual investigator grants. Although I believe that these cross-directorate programs are extremely important, I think it is also necessary to have an accurate assessment of the funds available directly for research support. Budget numbers excluding cross-directate programs indicate that the request for unrestricted research funds for the Solid State Physics Program is ~ 3% higher than the 1989 budget, that for the Low Temperature Program is ~ 3% higher, and that for the Condensed Matter Theory Program is ~ 7% higher. Since the outlook for the NSF budget request at this time is quite gloomy, it is very probable that any increase for these programs will be well below the projected inflation rate of 4 - 5%.

As condensed matter enters the 1990's, we can expect the growth of interest and opportunity to continue and the funding situation to get worse. A strong indication that the growth will continue for some years is given in the figure below, which is taken from the Report of the APS Committee on Opportunies in Physics entitled: **The Physics Faculty Workforce Survey - 1988**. It shows the number of Ph.D. physics departments seeking faculty in the indicated subfields and indicates that of the approximately 170 Ph.D. granting departments, 108 (about 2/3) are looking for condensed matter experimentalists and 64 (more than 1/3) are seeking condensed matter theorists.

Number of Ph.D. Physics Departments Seeking Faculty in Indicated Subfields



Since large numbers of graduate physics departments are choosing to hire new faculty in the area of condensed matter physics (considerably more experimentalists and theorists are being sought in this subfield than in any other subfield), it seems almost certain that this area will continue to grow, both in absolute numbers and also as a percentage of the total physics faculty.

Why do physics departments continue to hire condensed matter physicists when the prospects for funding are so poor? I'll mention a few reasons that I know of; you may have additional insight into this. One reason has to be the current concern about our national competitiveness. No other area of physics combines the fundamental and the pragmatic in such a symbiotic manner. For this same reason Erich Bloch continues to use the successes of condensed matter and material science to try to convince Congress of the need for an increasing NSF budget. It enables him to argue for support for pure science and economic competitiveness at the same time. In addition, many states are attempting to build up their high-tech industry, and a solid scientific and engineering education infrastruture is seen as a necessiiy in this endeavor. Condensed matter physics is often an inherent part of these new university - industry relations. Finally, graduate students continue to flock to this area. As mentioned before, in many departments there are not enough faculty in condensed matter to satisfy this demand, so the internal pressures are also strong to add people in this field.

What happens to people in a burgeoning field like condensed matter physics when it is grossly underfunded? When well-known and successful physicists are losing their funding and having to let post-docs and graduate students go, and when those entering the profession see almost no hope of getting funded, yet lack of funding means denial of tenure and blocked careers, morale is bound to plummet. Morale in the university condensed matter physics community is exceptionally low at the present time. Probably the most devastating long term effect of this is that many of the best and brightest graduate students are eschewing careers in academia and chosing industrial jobs; they see no reason to submit themselves to the overwhelming pressures of the competition for external support.

Should we sit back and relax, as some have suggested, and see this process as a natural outcome of a field that is growing too fast and therefore must slow down? This would seem to be a dangerous reaction if we look at the broad picture. As you've seen from the projections shown earlier today, the number of science majors is expected to fall rapidly in the 1990's. This will be caused both by the declining student-age population and by the increasing proportion of that population that will be made up of minorities that have traditionally not chosen scientific careers. We can expect our graduate programs to become more dependent on foreign countries to supply our graduate students. In addition, roughly one third of all physics faculty members will retire in the 1990's. This hardly seems like an appropriate time to shut down research programs and turn our bright young people away from academic careers in physics. I think the answer to the question that I posed has to be a resounding: **NO!** We must continue to work for more financial support for this very exciting field of physics.

Physics in the SSC Era

Roy Schwitters

Director, Superconducting Super Collider (SSC) Laboratory

Life in a Modern High Energy Physics Collaboration

The Superconducting Super Collider (SSC) will have a major impact on graduate physics education in the decades ahead. The good news concerning life in a modern High Energy Physics (HEP) collaboration is that there are great physics opportunities; a large, diverse group of experts/colleagues that we can work with and learn from will form; and there will be a broad range of technical activity taking place.

On the other hand, the bad news is that we are working with long-range time scales; there is a possibility of tyranny – individual versus majority; the question as to who will do "service" jobs must be answered; there will be the problem of remote sites involving much travel; and, finally, who will be recognized as authors, who will go to the papers with new research.

What Can Be Done?

The basic principle is that HEP research in the SSC era must be fully embedded in the research universities. We need the best and brightest graduate students, post-doctoral students, and professors.

We should be prepared for possible changes in the HEP community, including thinking up new ways to establish authorship of papers. We need to concentrate on livelier literature and assigning proper credit. We also need to create new ways to participate in collaborations. Students and junior faculty can access running experiments as well as plan for the future.

Possible Changes in Physics Departments

Changes we need to consider are: 1) permitting longer leaves-of-absence for faculty, approximately two years, while at the same time strengthening infrastructure at home institutions; 2) changes in the Ph.D. requirements to recognize that instrumentation efforts and data analyses may be from different experiments; and 3) making academic appointments in instrumentation and accelerator physics.

Possible Changes in the Laboratories

Changes in the laboratory might include providing a home away from home for students and professors including courses and lectures; influencing collaborations to bring effective change; providing competitive fellowships for university-based post-doctorals, junior faculty; and providing recognition for promotions. We need to broaden our areas of academic research such as superconductivity, materials, engineering, tunneling, etc.

Conclusions

- Physics interest in the SSC continues to grow.
- Large detector collaborations of HEP can be a very challenging and rewarding place for physicists to work, but changes are needed to attract more of the best and brightest.
- Strong infrastructure at the home institution is important for a university group to make a substantial impact on research and to fulfill educational goals.
- SSC funding is by no means assured. We need the support of the entire physics community.

Graduate Student Recruitment

Eugene Loh
University of Utah

We examine here the production of physics graduate students and the demand for Ph.D. physicists. In a recent AIP Education and Employment Statistics Division publication, *Graduate Education Today,* there is a clear indication that we are producing about 1,100 Ph.D. physicists, down from 1,600 in the late 1960s. In the 1988 APS-COP publication, *Profile of the APS Membership,* the median age for university physics faculty members and for physicists working in industry are 47 and 42 years, respectively. The same report gave the total number of Ph.D. physicists employed in academe and in industry to be about 22,000. The distribution is about 45 percent working for government laboratories and industry and the rest in academe.

There are two observations:

1. At the present Ph.D. rate, it will be difficult to fill the positions created by expected retirements in academe. In those cases, there is a further selection process through the post-doctoral stage.
2. If we assume that the number of physicists employed by industry and by government laboratories does not grow as it has in the years past, there still will be a shortage of Ph.D. physicists, albeit the shortage would be less severe.

There are two ways to solve this shortage problem which has already landed at our doorstep. The immediate way is to mount a vigorous campaign to recruit foreign students. America has always benefited from the influx of immigrants. On the other hand, if we examine our human resources carefully, we note that if we are able to attract female and minority students into physics, our shortage problem would be solved for a long time to come. The long-term solution lies in our resolve and our determination to improve our method of recruiting physics students.

Here are a few suggestions for us to ponder about recruiting graduate students:

1. Physicists should define their roles in industry and government laboratories. If possible, we should expand our participation in industry in well-defined and publicized areas. This would enable the prospective students to visualize various possible career paths that are open to them. The career paths in academe are well publicized.
2. Universities and colleges should participate in more vigorous recruiting campaigns.
3. Organizations such as APS and AAPT could:
   a. Locate scholarships, summer jobs, and training opportunities from industry.
   b. Organize workshops and school visits to attract minorities and women students.

Today, students take a careful look at what life and career can offer. We must respond to their requests.

OPPORTUNITIES IN THE INFORMATION PROCESSING AND TELECOMMUNICATIONS INDUSTRY

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We are now in the midst of the "Information Era," where rapid advances in information creation, use, distribution, and storage are changing the way individuals lead their lives and institutions conduct business. At the forefront of this advance is the miniaturization of electronics and storage media and the increased information-carrying capacity of communications systems. Some people say that the Information Era is in its infancy, others say it is maturing, and others think it is mature. But no-one thinks it is static. Everyone agrees that there is vast room for technological improvement from the standpoints of hardware devices, software, and systems architecture. This paper will address some directions in hardware evolution and the opportunities for physics research in support of these directions.

Future improvements in device technology for the information processing and telecommunications industry will depend heavily on research and development activities of scientists, many of whom will be trained in physics. Support for this prediction comes from the examination of historical trends in information processing technology. An examination of the history of the miniaturization and integration of storage devices, starting in the 1950s, reveals a remarkable pattern of progress. Figure 1 plots, as a function of time, the number of atoms needed to store a bit of information using various storage technologies.[1] Over 35 years, there has been a decrease of *11 orders of magnitude* in the requisite number of atoms. If this trend continues for the next 20 years, by the year 2010 *only 1000 atoms will be needed to store a bit of information.* Equally remarkable is the progress in logic devices. An important figure of merit is the energy dissipated during a logic operation. As logic devices work at higher speeds and at higher densities of integration, a practical limit is imposed by the need to remove the dissipated heat. Figure 2 displays, as a function of time, the energy dissipated per logic operation using various technologies, from discrete relays to integrated circuits of transistors.[1] Over 45 years, there has been a decrease of *13 orders of mag-*

nitude in energy dissipation. If this trend continues for the next 20 years, by the year 2010 *the heat dissipated per logic operation will be only 1 order of magnitude larger than kT at room temperature.* The implications of these trends are that device technology will need to incorporate devices that are fully quantum mechanical in their behavior, statistical fluctuations will be more important, low temperature operation will become routine, and devices will have to be characterized using new tools with atomic resolution. Clearly, much of the science underlying this technology development, and much of the technology development itself, and perhaps even much of the manufacturing, will require the intellectual discipline and training of a Ph. D. in physics.

Picking just one area of opportunity for further elaboration, continued progress in miniaturization and integration will depend on better control of materials and processing technology. As devices shrink in size and more of them are packed into the same volume, surfaces and interfaces have to be better controlled and boundaries have to be more abrupt. The need to fabricate boundaries with atomic-scale control is in the not-too-distant future. The information processing and telecommunications industries must support materials and processing sciences to acquire the knowledge base needed for such exquisite control of materials and processing technology. Thus, the arrival of the scanning tunneling microscope (STM)[2] and its cousin the atomic force microscope (AFM) could not have come at a more opportune time.

An example of use of the exquisite capability of the STM to measure a fundamental chemical physics process at a semiconductor surface is provided by the study of atom-resolved surface chemistry on silicon.[3] An STM was used to take atom-resolved micrographs of the Si(111)-(7x7) surface prepared in the clean state and after successive exposures to ammonia. As the silicon surface chemically reacted with ammonia, STM images of the various atomic sites at the silicon surface showed changed contrast, depending on the site and the level of exposure. Using the STM to take current *vs* voltage spectra at the various sites, the local electronic structure of the clean surface and its modification by the surface reaction could be determined. Thus the spatial distribution of surface reaction could be studied on an atom-by-atom basis. Significant differences in reactivity between various dangling-bond sites were discovered and related to the differing electronic and geometric structure at the different sites. Studies such as this point the way to monitoring and even controlling the production of future devices, on an atom-by-atom basis.

An example of the sensitivity and spatial resolution capability of the AFM is provided by the study of atomic-scale friction.[4] An AFM measured the friction acting on a tungsten wire tip sliding on the surface of graphite. The tip slipped and dragged in a periodic motion that corresponded to atomic-scale features having the periodicity of the graphite lattice. This extraordinary ability to image frictional forces with atomic resolution points to the possibility of measuring nonconducting device structures that are fabricated with atomic scale dimensions. Storage technologies based on AFM-type of writing and reading techniques, with much higher densities than today's technologies, are attractive possibilities.

This brief discussion of measurements of surfaces with atomic-scale resolution is meant to illustrate the scientific opportunities and needs that are engendered by miniaturization and integration in electronics technology. But the opportunities and challenges are much broader. As we study the behavior of smaller versions of existing devices and devices based on different scientific principles, we will have to take quantum mechanical phenomena into account. Smaller devices will make statistical fluctuations more significant, and smaller cross sectional wiring will make wire resistance more significant. Both of these effects will drive device technology to lower temperatures, and in the next decade, we can expect to see commercial computer CPU's operating at liquid nitrogen temperature. In the time domain, new techniques, such as those based on femtosecond laser technology, will reveal details about the dynamics of electronic processes and materials modification.

Electronics hardware evolution during the next decades will provide exciting challenges for physicists, working by themselves and in inter-disciplinary projects together with chemists, materials scientists, and device engineers. Ph. D. - granting graduate departments in the United States should position themselves to take advantage of this opportunity. It is imperative that more departments develop courses and enter into or enlarge research programs that are relevant to microelectronics, storage technologies, optoelectronics, and communications. The challenge for our Ph. D. programs is to produce scientists who are interested in and trained to advance the hardware technology that will drive the information processing and telecommunications industry.

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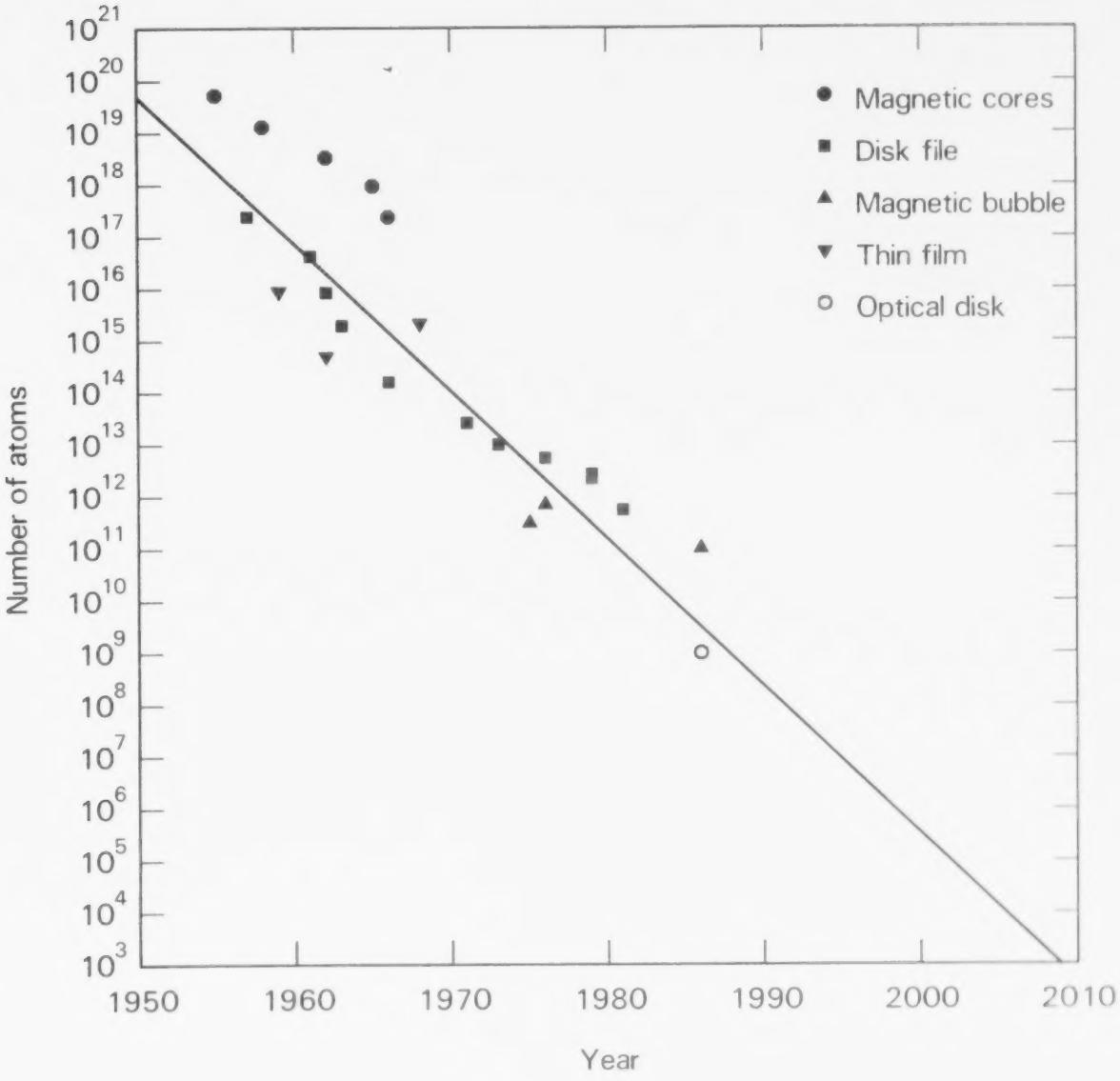

Figure 1 - The number of atoms used to store one bit
(courtesy of R. W. Keyes)

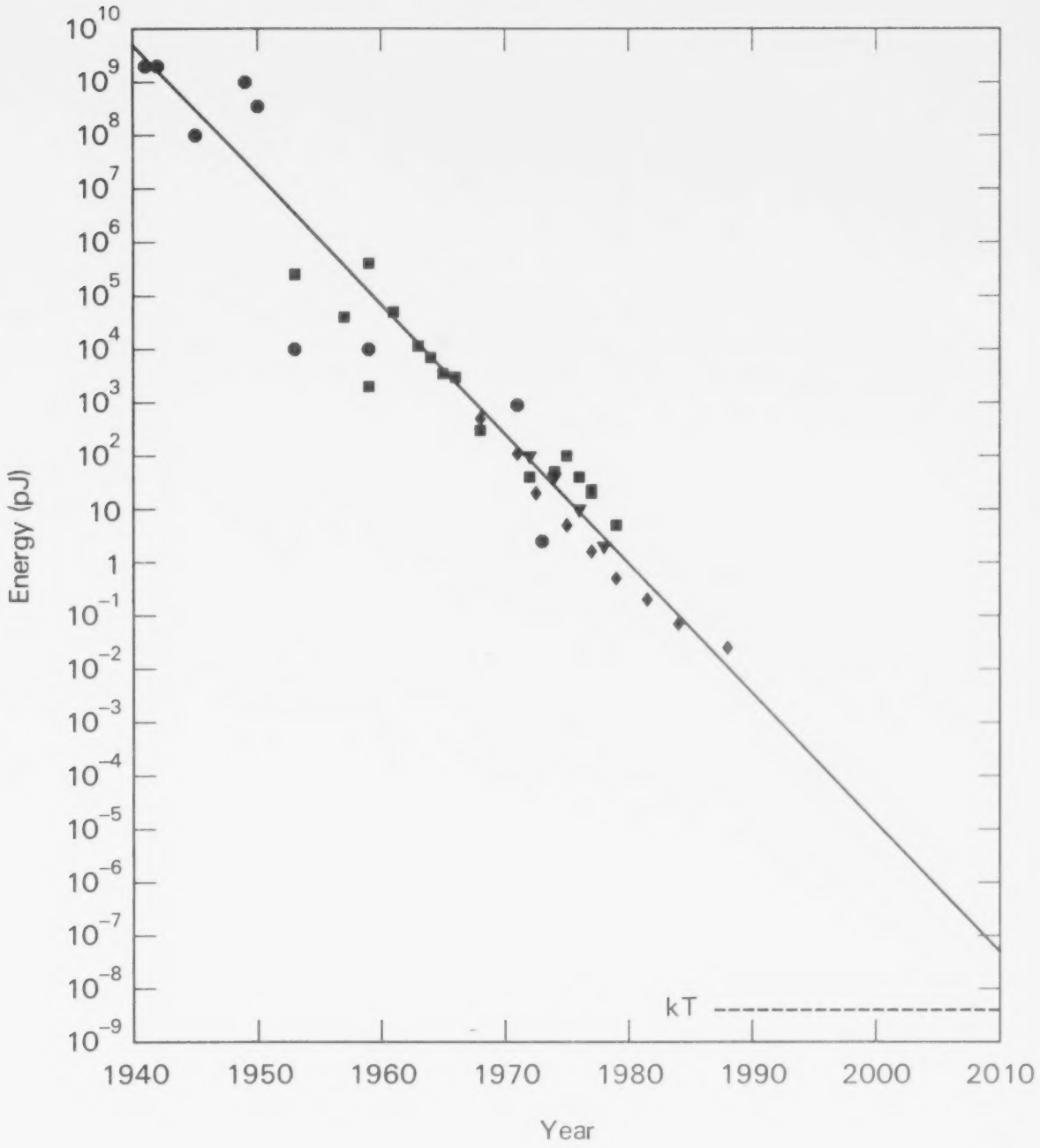

Figure 2 - Energy dissipation per logic operation
(courtesy of R. W. Keyes)

Comments on the Future Role of Computers in Physics Education and Research

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Numerical Computation

At present the use of computers for numerical calculation is essential to a substantial portion of experimental physics research. Computers are routinely used for the design of experiments, the control of experiments themselves, and the analysis of experimental data. For example, in the field of High Energy Physics, computers are used extensively to design accelerators. This involves the use of Maxwell equation solvers to design both radio frequency cavities and superconducting magnets. It also involves Newton equation solvers to study orbit stability. Next, all modern accelerators are run under computer control. Finally, the design of High Energy particle detectors and the analysis of actual events in these detectors involve extensive numerical Monte Carlo simulation.

The use of computers to perform numerical computation is equally important to many areas of theoretical physics. Examples that readily come to mind include lattice gauge theory calculations in elementary particle physics, many body calculations in nuclear physics, band structure calculations in solid state physics, the simulation of a host of different systems in the burgeoning field of dynamical systems and chaos, and the extensive use of various codes in plasma physics.

No doubt the listener or reader can think of many more applications of computers to perform numerical computations in his or her favorite areas of experimental and theoretical physics. Moreover, we would all agree that the use of computers for numerical calculation in both experimental and theoretical physics is growing at an ever increasing rate.

Symbolic Computation

The above discussion concerned the familiar use of computers for numerical computation. It is less well known that computers can also be used for symbolic computation. Programs presently available for this purpose include REDUCE, MACSYMA, SMP, MUMATH, DERIVE, SCRATCHPAD, and MATHEMATICA. To a greater or lesser degree, these programs are capable of carrying out all routine algebraic and matrix manipulations, can manipulate power series and carry out simultaneous power series expansions in several variables of all standard functions, and can differentiate and integrate standard functions. Some also offer provisions for the user to implement algebraic and analytic procedures of his or her own design.

For the purpose of stimulating thought, I conjecture that in the future the use of computers for symbolic manipulation will be as important as, or even more important than, the present use of computers for numerical calculation. For example, in the future, all routine and not so routine algebraic and matrix and calculus-like calculations will be done using symbolic computation. Moreover, many analytic calculations that would not ever be attempted by hand will become common place. For example, some of the Newton solvers mentioned above for computing trajectories in high energy accelerators make use of Lie algebraic methods. These Lie algebraic calculations were in turn carried out using computer symbolic manipulation. Had these same symbolic computations been carried out by hand, they would have required hundreds of man-years of work, and also would have been much more error prone.

Effect on Physics Education

Assuming that my conjecture is correct, what does this imply for future physics education? I will not attempt to speculate on what the influence will be on *how* physics will be taught. That question is still unresolved even for the case of the use of computers to do numerical computations. However, I will venture a few comments on *what* should be taught: First, students should acquire a knowledge of what I will call formal concepts and structures. That is, they should be taught about the *qualitative* behavior of the solutions to ordinary differential equations (e.g. Newton's equations) and partial differential equations (e.g. Maxwell's equations). They should also learn *qualitatively* about linear vector spaces and linear operators (matrix and vector manipulations, eigenvalues, etc.). Much of this material either is, or is an extension of, what we often refer to as physical intuition. Next, students should be taught about computer tools that implement these formal concepts and structures in a concrete way. They also should understand roughly how these tools work. In general, these tools will involve both numerical and symbolic computation. This computation should be carried out in the classroom before their very eyes, and should also be a component in homework. Finally, students should be taught how to spot check that the computer tools they are using are actually working, and the answers being produced are correct. For example, are obvious symmetries honored, are known constants of motion actually constant, are special simple cases handled properly, etc.

Summary of Panel Discussion 1: Issues in Graduate Education

Douglas Fitchen
Cornell University

The panelists of Panel Discussion 1 were Robert Resnick, past president of AAPT and an early promoter of this conference; Terence Porter, a division director at NSF; Eugene Loh, physics chair at the University of Utah; James Wynne, manager of biological and molecular science at IBM Yorktown; Alex Dragt, former chair at the University of Maryland; and Robert Swenson, chair at Montana State University. The moderator was Douglas Fitchen, chair at Cornell University.

The first panelist, Bob Resnick, presented his remarks in the opening session Monday morning, setting out the goals and agenda for the conference. The other five panelists gave brief presentations as part of the two-hour session Monday afternoon. Each panelist focused on one issue or one particular perspective to stimulate discussion on that topic. There was time between talks for lively and wide-ranging discussion.

Some of the topics which evoked the most lively discussion were: the pros and cons of increasing reliance on foreign graduate students; causes and cures for the increasing time to earn the Ph.D.; and probable factors that discourage students, especially women and minorities, from pursuing graduate study in physics. By the end of the session, most of the topics on Resnick's list of "issues" had come up at least once. All present had a chance to share impressions and first-hand experiences in a variety of areas important for the future of graduate education in physics.

THE FEDERAL ROLE IN SUPPORT OF DOCTORAL PROGRAMS

Brian B. Schwartz

The American Physical Society and

Brooklyn College of the City University of New York

I. INTRODUCTION

Much of the support for graduate students and their research comes from federal agencies. As a result, it is extremely important to have an overall view of their programs which relate to graduate education, as well as a projection of the outlook for the agencies' funding in the future. Since most of the support in Physics comes from three main federal sources, The National Science Foundation, The Department of Energy, and The Department of Defense, representatives of these federal agencies were asked to speak at the Topical Conference on Issues in Graduate Physics Education and Research held on 22-23 May 1989.

The five speakers in a session entitled "***The Federal Role in Support of Doctoral Programs***" were Bassam Z. Shakhashiri, Director, Directorate for Science and Engineering Education, NSF; Marcel Bardon, Director, Physics Division, NSF; Al Shindler, Director, Materials Research Division, NSF; Ted G. Berlincourt, Director, Research and Laboratory Management, Office of the Director, Defence Research and Engineering, DOD; and John O'Fallon, Director, Division of High Energy Physics Programs, DOE. This report will give an overview of their presentations. It should be well noted that the selection of the material include in this report, as well as some of the items emphasized have been influenced by the biases and opinions of the author.

This report will first review a series of overall themes which relate to the general context of all the talks. This will be followed by specific comments and information gleaned from the talk of each of the speakers. In an Appendix, we present data on the actual funding for FY 88, the request and current funding for FY 89 and the request for FY 90 as of spring 1989 for four federal agencies. It should be noted that in many agencies the actual FY 90 funding has already been reduced by congressional actions below that of the request. The four agencies covered include, The National Science Foundation, The Department of Energy, The Department of Defense and the National Aeronautics and Space Agency.

II. GENERAL THEMES

While all the speakers presented data and projections on their particular agencies, there were some general themes which were emphasized. Listed below are some of these general themes.

1. ***The most important action by the physics community is to work towards helping to increase the total overall funding for science.*** This action would, in the words of a previous U.S. president, raise the "ship of physics" along with all the other sciences. Obviously, when there is more funding in physics, this supports a larger number of researchers and their students. This also results in a greater number of specific graduate fellowships. As many of the representatives stated, the objective is to make a bigger science pie. The agency representatives have a wider understanding of the budgetary pressures from the other sciences. They felt it would be counter-productive to compare or complain about growth rates in physics as contrasted with other areas of science. All agreed that there is a shortage of funds for many worthwhile physics projects.

2. ***The physics community must make a persuasive argument for support of its programs and communicate this directly to the agencies, the Congress and the public.*** Past reports on the state of physics such as the Bromley report in the 70's and the Brinkman report in the 80's, reviewed all the marvelous basic physics and opportunities according to the subfields of physics. Nowhere within the reports or their supporting materials did the physics community or the subfields make any significant attempt at priorities. As a result, essentially a shopping list was prepared which was not all that helpful to either Congress or the agencies in these times of tight budgets. While the speakers recognized the difficulty of getting the physics community to set priorities, the alternative of not setting priorities meant that the Executive Branch, Congress and the agencies would be forced to make the decisions. The American Physical Society recently established the Physics Planning Committee to develop information and create an active dialogue among the various subfields of physics. It was felt that had such a committee been in place earlier, there would not have been such vocal and internecine arguments between the high energy physics and the condensed matter physics community. It was agreed by all that this internal fighting was detrimental to all of physics as well as the general concept of increasing the overall funding of science.

3. ***The physics community must work toward a secure and stable environment for basic research funding to insure opportunities for career development and growth.*** There was a general feeling that the present uncertainty and tight funding situation is having a detrimental effect on the flow of talent into careers in science and mathematics and is, in too many cases, cutting short the productive research careers of capable scientists. Anecdotal information indicated that the only way to fund the young incoming research scientist, was to terminate funding for capable "older" (in some cases, in mid-career) scientists. This situation is

obviously a waste of productive talent and a strong disincentive to getting the best and brightest of our students to pursue a research career in science.

4. ***The physics community must be concerned with both the education of future sciences and the general science literacy of the public.*** The National Science Foundation has analyzed the pattern of attrition of students away from careers in science and engineering as they move through the education pipeline (See. Fig. 1). Of the 4,000,000 students in the 10th grade in 1977, less than 10,000 will be awarded the Ph.D degree in Science and Engineering by 1992. There is a need to give all capable students a chance for a career in science and engineering as well as ensure the scientific literacy of the non-science major students who exit the pipeline. Science and engineering in general and physics in particular does very poorly in the education of women and minorities. The future demographic indicates that these groups must be nurtured in order to have a strong and competative U.S. effort in science.

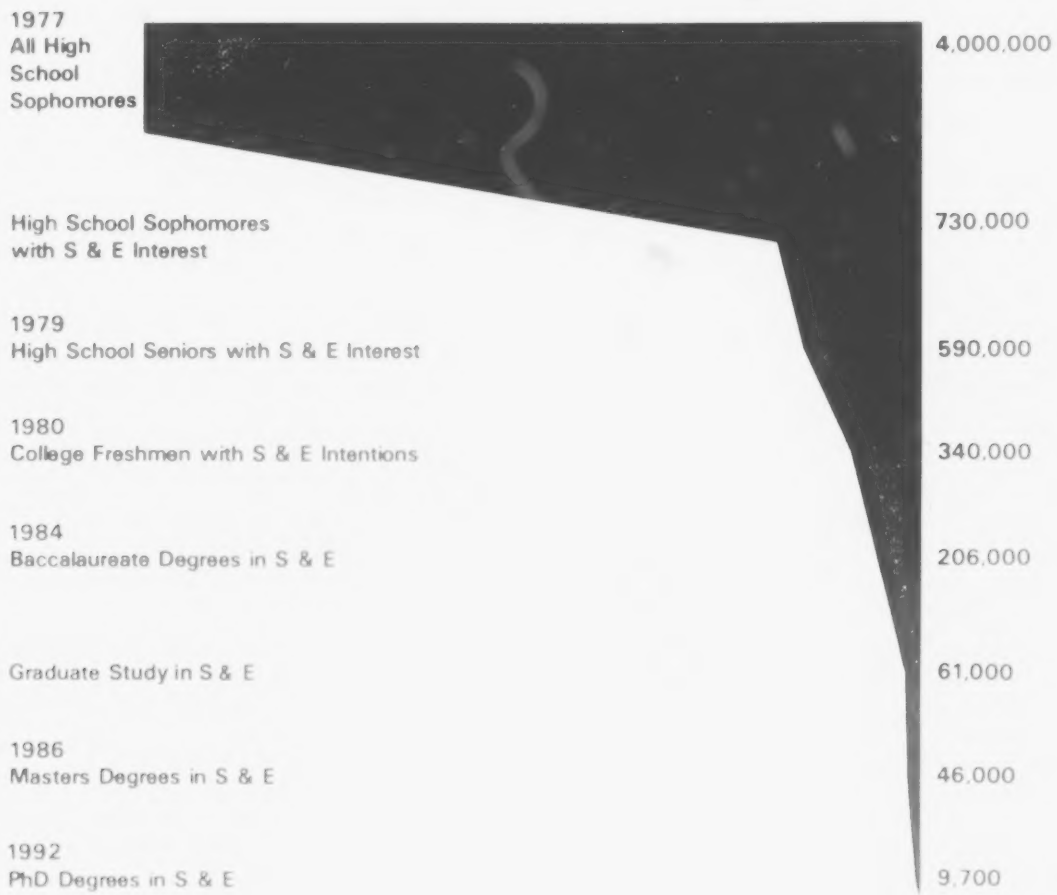
III. SPECIFIC COMMENTS OF THE SPEAKERS

Each speaker presented a review of their agency's role in physics research and education with an emphasis on graduate student issues. Listed below in the order of the speaker's presentations are some of the facts and the concerns related to graduate education.

1. **Dr.Bassam Shakhashiri:** Speaking the viewpoint of science education, Dr. Shakhashiri expressed concerned with the flow of talent into careers in science, engineering, and mathematics. A second major concern was the communication of science to the public and the overall scientific literacy of the nation. Specific emphasis was given to expanding and emphasizing the education and the opportunities for women and minorities.

Figure 1.

Science & Engineering Pipeline, from High School through Ph.D. Degree



Analysis of the 4 million students in the 10th grade in 1977 shows the pattern of attrition as they move through the educational pipeline. Approximately 9,700 or 0.24 percent are expected to attain the Ph.D. in science and engineering.

Source: National Science Foundation

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There was great concern with the leakage of talent away from science careers. In FY 89, the NSF budget within the Directorate for Science and Engineering Education was 170 million. Although the FY 90 budget request was for 190 million, Congress is likely to increase the budget to 210 million. In the general scheme of the overall NSF budge, Dr. Shakhashiri felt that eventually about 20% of the NSF budget should be in the area of education. If one assumes in a few years the NSF budget will grow to 3 billion dollars, then education should receive 600 million. Dr. Shakhashiri indicated that such a budget level could support 300 million in pre-college science education, 200 million undergraduate science education, and 100 million in graduate students and post-doctoral support.
(See pp. 94–105.)

Dr. Shakhashiri emphasized that in testifying before Congress, his arguments for support of science research and education emphasized the impact of science on national security, economic competitiveness and the strenthening of an educated democratic populace. While he also mentioned that support also allowed for the curiosity, enlightenment, joy, fun, pleasure, satisfaction and employment of the scientists, it is the impact of science on the nation which provides the basic foundation for support. Dr. Shakhashiri discussed the pipeline effect (See Fig. 1) in science and engineering and emphasized both increasing the number of scientists in the pipeline and the science literacy of those who leave the pipeline for other careers. The need for high quality future scientist is clear. Five major projects, the superconducting supercollider, the space station, the mapping of the human genome, AIDS and SDI, are making increasing demands on the supply of scientists. Again he emphasized the important role women and minorities must play in meeting these demands.

2. **Dr. Marcel Bardon:** As Director of the Physics Programs at NSF, Dr. Bardon managed a budget of approximately 122 million dollars in FY 89. The Physics Programs has a request budget of 130 million for FY 90, an increase

of 6.1%. The areas supported by the Physics Division include elementary particles, intermediate energy physics, nuclear physics, atomic, molecular and optical, theoretical and gravitational. The details of the budget division are included in the Appendix. Much of the support is to the individual researcher who through the grants, supports graduate students and their research. Dr. Bardon emphasized that the 41 million spent in FY 89 on elementary particle physics, supported mostly university investigators who made use of national facilities maintained and supported by the Department of Energy. Thus, almost all these funds were for direct basic research and graduate education. Dr. Bardon was greatly in favor of the physics community developing a mechanism to aid the federal agencies with developing and setting priorities. He emphasized the need for cooperation among the physics sub-disciplines and was greatly in favor of worthy to increase the overall funding for science. He noted that in the FY 90 budget request, the proposed increase in physics programs was only 6%, whereas the overall NSF FY 90 budget increase request was 14%. He observed that there were so many pressing demands on the NSF budget that the overall increase in physics was likely to remain below the general NSF increase. The community however, should actively support the building of a bigger budget for all of science.

3. **Dr. Al Shindler:** As Director of the NSF Division of Materials Research (DMR), Dr. Shindler's division provides support for research to advance the fundamental understanding of materials. The general areas of support, which of course overlap, are condensed matter physics, materials chemistry, and materials science and engineering (which includes metallurgy, ceramics, polymers, and electronic materials). The DMR supports three different funding modes individual disciplinary research, multidisciplinary research and national facilities. In the multidisciplinary mode, there are three funding levels and structures: 1) Material research groups (MRG) focus on a single topic with funding levels

of 400 - 900K. An average group consists of six faculty members, six students, and two post-doctorals. Fifteen such groups are currently being funded in thrust areas such as magnetism, polymer, glasses, ceramics, epitaxy and others. 2) Materials research labs (MRL) support major materials research topics with funding levels of 1 to 5 million. At present, nine MRL's are being supported with a total of 320 faculty members, 400 students, and 90 post-doctorals covering 40 major thrust areas. The MRL research topics include surfaces, interfaces, catalysis; microstructure and structural materials; polymer science and engineering; optical, optoelectronic materials; phase transitions; disordered materials; and high temperature superconductivity. 3) Science and Technology Centers (STC) are committed to a strong, materials-related unifying research focus. Eleven STC's were established in 1989 and are in the start up phase. Four of these centers are managed by the Division of Materials Research. These are: Superconductivity (Illinois-Chicago-Northwestern-Argonne); Quantum Structures (UC-Santa Barbara); Advanced Cementitious Materials (Northwestern-Illinois-Purdue-Michigan-National Institute of Standards and Technology (NIST)), and Polymer Adhesives and Composites (Virginia Tech). The FY 89 funding for these four STC's is 10.2 million and has the participation of 108 faculty, 75 students, 35 post-doctorals. Each STC has strong links with industry. The DMR also supports five national facilities, the Cornell High Energy Synchrotron Source, the Wisconsin Synchronization Radiation Center, the NIST Center for High Resolution Neutron Scattering, the MIT Francis Bitter National Magnet Laboratory and the Arizona State Center for High Resolution electron Microscopy. The total FY 89 budget for the DMR is 115 million and the FY 90 budget request is for 135 million. While this increase seems large, there is a special request for 12 million dollars to initiate a four-year program to build a high magnetic field facility. Dr. Shindler stressed repeatedly that physics support can be found in almost every area of the DMR programs.

This year in response to the need and opportunity, the DMR developed a special initiative program in superconductivity. (See pp. 106–107.)

4. **Dr. Ted Berlincourt:** As Director of the Research Lab Management in the Office of the Secretary of Defense, Dr. Berlincourt reported on the Department of Defense funding of basic science. Unlike other federal agencies, it is somewhat more arbitrary and difficult to separate out basic research from more applied research areas and testing, evaluation and large systems engineering. Dr. Berlincourt estimated the FY 90 DOD request for all of basic research funding as approximately 930 million.

The funding of physics was not broken down in detail. Dr. Berlincourt emphasized that nearly every area of DOD research contains a significant physics component. Dr. Berlincourt was concerned that DOD support of basic research is well below the level of the 1960's. Even the recent defense department budget buildup has not returned basic research funding to its previous levels. He further noted that currently about 50% of basic research funding is spent at the universities with the other in industry and government laboratories. This represents a significant increase in the university percentage which had dropped as low as 35% in the 70's. As an example of the flexibility and timeliness of DOD funding, Dr. Berlincourt noted that currently the DOD is investing a total of 73 million in superconductivity with 58 million in high temperature materials and 15 million in low temperature materials. In addition to the armed services, superconductivity gets support from DARPA and SDI. The DOD is especially concerned with science education and the overall quality and quantity of scientists and engineers. The DOD has programs in pre-college, college, graduate and post-graduate education. Currently there are 400 graduate fellowships being supported as well as 8,000 graduate students obtaining support from university grants. The DOD has developed a new office of Force Management and Personnel in the Office of the Secretary of Defense.

Issues of concerns include projections of the work force of scientific and technical personnel, increasing the participation of women and minorities, and the balance between foreign nationals and U.S. students studying science. There is a recognition that the situation in the pre-college years is critical as demonstrated by the pipeline effect. Dr. Berlincourt emphasized that the DOD budget would remain tight in the years ahead. The physics community should develop basic research opportunities and apply pressure, where appropriate, to increase 6.1 basic research DOD funding. The U.S. future, in terms of its competitiveness and defense capabilities, depends critically on science and engineering education, research, and human resources.

5. **Dr. John O'Fallon:** Although Dr. O'Fallon represented the Department of Energy (DOE), his main area of expertise is in the area of high energy physics. The DOE is greatly concerned with the continuing decline in the quality and quantity of U.S. scientist and engineers. The Office of Energy Research in FY 89 spent approximately 2.2 billion with about 500 million in Basic Energy Science which includes physics, chemistry and materials sciences, 559 million was allocated for High Energy Physics, 261 in Nuclear Physics and 346 million in the Office of Fusion Energy. The new Office of the Superconducting Supercollider had approximately 100 million FY 89. Other DOE physics-related funding supports the major DOE facilities as well as university facilities and instrumentation. Science education plays a large role in DOE programs. A vast number of principal investigators at universities support graduate education through direct funds in their grants. It is estimated that the DOE supports 4000 grants for 477 million dollars in FY 89. The DOE also supports competitive Energy Fellowship which focus on specific DOE needs such as computer engineering and waste management. In the future, fellowship funding might support the development of accelerator physicists. About 725 post-doctoral positions are supported with about 1/3 of them in high energy physics and nuclear

physics. Of the high energy physics supported at universities, about 2/3 is from the DOE and 1/3 from the NSF. Much of DOE high energy physics support is for DOE user facilities such as Fermilab, the Stanford Linear Accelerator, and the AGS at Brookhaven. About 100 universities participate in the high energy physics user facilities which are used by over 1700 faculty members and 800 students. In high energy physics, a panel is considering the future modes of research in experimental particle physics. This panel will consider the increasing shift from research and equipment development on campus to the high energy physics facilities. This is due in part to the decline in the technical support base at the university and the erosion of the home university facilities. The panel will recommend upgrading instrumentation and research facilities at the university and re-building the technical support staff. The DOE has many national facilities such as Argonne, Oak Ridge, and others actively involved in all levels of science and engineering education. Many formal and informal education programs exist at all levels form pre-college to post-doctoral. In FY 90, DOE has specifically contributed 12 million in support of undergraduate college education, and 13 million for support of historically black colleges and universities. Other programs include research internships, semesters and summers at national laboratories, and pre-college education for students, teachers and parents. The education goals of the DOE include, strong support for basic research with an annual increase of 10% in energy research, programs aimed at pre-college educations, and the development of a scientifically literate population.

A lively discussion followed the presentations. The four general themes discussed earlier were emphasized. These were specific concerns on how to educate and maintain high quality pre-college teachers. There were encouraging signs such as the special science high school initiatives in North Carolina and the Education Center to be developed at Fermilab. It

was hoped that more U.S. students would choose careers in science and that stable and predictable funding would make science careers attractive and rewarding. (See p. 108.)

APPENDIX

The speakers presented data on their own agencies and usually emphasized mostly the areas of physics within their respective divisions. Listed below is data on the budget of four federal agencies for physics-related research. This data was gathered by Irwin Goodwin and reported on in the May 1989 issue of Physics Today.

TABLE I National Science Foundation Physics-Related Research

TABLE II Department of Defense Basic Research Funding (Strategic Defense Initiative)

TABLE III Department of Energy Physics-Related Research

TABLE IV NASA Physics-Related Research

REFERENCES

Tables I–IV are reprinted with permission from *Physics Today* 42 (5), Irwin Goodwin, "Numbers Game: Bush's 1990 R&D Budget Uses Reagan's Figures in Making Deals," pp. 43–49, ©1989 American Institute of Physics.

Table I.

National Science Foundation physics-related research

	FY 88 actual	FY 89 request	FY 89 current	FY 90 request
	(millions of dollars)			
Mathematical and physical sciences				
Physics				
Elementary particles	44.7	40.4	41.0	41.4
Intermediate energy (nuclear)	17.8	21.3	19.7	20.8
Nuclear	21.0	23.6	22.7	23.9
Atomic, molecular and optical	13.1	14.3	13.5	14.4
Theoretical	15.2	16.6	15.9	17.1
Gravitational	8.9	9.7	9.8	10.4
Total physics	117.9	126.0	122.6	130.0
Materials research				
Solid state physics	11.6	12.2	12.0	12.9
Solid state chemistry	8.8	9.2	8.8	9.4
Low-temperature physics	8.2	8.8	8.7	9.3
Condensed matter theory	8.8	9.3	9.3	10.4
Metallurgy	9.0	9.4	9.3	10.0
Ceramics and electronics materials	7.7	8.2	8.3	9.1
Polymers	8.1	8.7	8.2	8.7
Instrumentation	4.0	4.5	4.0	4.7
Materials Research Laboratories	26.2	26.9	26.2	27.1
Materials Research Groups	7.4	8.9	8.1	9.1
National facilities	10.6	12.1	12.1	24.6
Total materials research	110.6	118.2	115.0	135.2
Mathematical sciences	63.8	67.6	65.9	76.0
Chemistry, including physical chemistry	94.0	98.6	96.6	103.4
Astronomical sciences				
Solar-system, stellar evolution and galactic studies	28.1	29.0	29.0	31.2
National Astronomy and Ionospheric Center	5.8	6.2	6.1	6.1
National Optical Astronomy Observatories, including Kitt Peak and Cerro Tololo	23.1	24.2	24.2	25.2
National Radio Astronomy Observatory	16.9	18.0	18.1	18.8
VLBA construction	11.6	12.0	12.0	12.4
Total astronomical sciences	85.8	89.5	89.5	94.0
Math and physical sciences and technology centers	—	—	13.7	14.8
Total mathematical and physical sciences	472.0	500.0	503.1	553.5
Geosciences				
Atmospheric sciences	48.7	52.5	49.6	55.2
National Center for Atmospheric Research	42.8	46.1	44.1	48.1
Upper atmospheric facilities	4.7	5.4	5.0	6.0
Earth sciences, including geophysics				
lithospheric studies and instrumentation	51.1	59.1	54.2	65.2
Ocean-sciences research	67.2	72.9	71.2	74.7
Oceanographic centers and facilities	37.2	41.2	43.6	45.1
Ocean drilling program	10.6	12.0	11.4	12.9
Arctic research program	8.1	10.8	10.1	12.8
Geosciences science and technology centers	—	—	0.9	1.0
Total geosciences	290.7	320.0	310.1	341.3
Antarctic research program	124.7	141.0	131.2	156.0
Computer and information science and engineering				
Computer and computation research	19.8	22.2	21.1	23.7
Information, robotics and intelligent systems	17.7	19.7	19.1	21.6
Microelectronic information and processing systems	13.1	15.9	15.0	19.0
Advanced computing/Supercomputing Centers	44.7	55.8	55.8	53.2
Networking and communications research	17.5	17.7	17.7	27.1
Cross-disciplinary activities	16.9	17.4	17.4	21.4
Computer science and technology centers	—	—	5.9	6.2
Total computer and information science and engineering	129.9	148.7	152.1	191.2
Science and Technology Research Centers		30.0	0.4*	20.0
Engineering Research Centers	33.3	39.9	38.0	45.7
Industry-University Research Centers	3.5	3.4	3.6	5.0
Science and engineering education				
Teacher preparation and enhancement	45.5	53.5	61.5	68.5
Learning materials and informal education	37.8	41.5	44.0	49.0
Undergraduate science, engineering and math	19.0	23.5	28.0	30.0
Research career development	18.0	11.0	11.0	18.0
Studies and program assessment	3.2	4.5	4.5	4.5
Total science and engineering education	139.6	156.0	171.0	190.0

*Also see line items for S&T Centers under mathematical and physical sciences, geosciences and computer science.

Table II.

Department of Defense basic research funding (6.1 budget category)

	FY 88 actual	FY 89 request	FY 89 current	FY 90 request
	(millions of dollars)			
Army				
Research, including physics and materials	167.6	173.5	172.7	175.9
Army laboratories discretionary research	—	—	—	9.1
Universities research initiative	—	—	—	21.9
Navy				
Research, including physics and materials	316.6	333.0	331.9	342.0
Navy laboratories discretionary research	22.6	23.8	23.4	24.4
Universities research initiative	—	—	—	24.3
Air Force				
Research, including physics and materials	185.2	189.4	189.4	187.6
Air Force laboratories independent research	15.0	10.2	7.0	7.7
Universities research initiative	—	—	—	24.9
Defense Advanced Research Projects Agency				
Research, including materials and computers	79.9	89.5	88.1	85.1
Universities research initiative	—	—	—	25.0
Office of Secretary of Defense				
Universities research instrumentation	24.6	—	—	—
Universities research initiative	85.0	95.0	141.0*	—

*Includes $46 million in "pork" projects earmarked by Congress for specific colleges and universities.

Strategic Defense Initiative (6.2 and 6.3 budget categories)

	FY 88 actual	FY 89 request	FY 89 current	FY 90 request
	(millions of dollars)			
Directed energy weapons	934.2	1029.9	819.8	1116.9
Kinetic energy weapons	773.2	936.3	773.1	1346.5
Surveillance, acquisition, tracking and kill assessment	934.5	1124.6	1100.7	1281.0
Systems concepts and battle management	461.5	639.9	506.5	780.9
Survivability, lethality and key technology	429.6	790.4	406.3	776.8
Boost surveillance and tracking system	—	—	—	262.0
Total SDI R&D program	3533.0	4521.1	3606.4	5564.1
Construction	59.2	90.5	83.0	12.9
Headquarters management	20.0	24.8	21.0	26.4
Total Defense Department SDI program	3612.2	4636.4	3710.4	5603.4
Department of Energy SDI program	353.8	402.0	336.0	311.0
Total SDI	3966.0	5038.4	4046.4	5914.4

Table III.

Department of Energy physics-related research

	FY 88 actual	FY 89 request	FY 89 current	FY 90 request
		(millions of dollars)		
High-energy physics				
Physics research	114.4	123.8	121.8	133.1
Technology research, including detectors	63.7	66.2	65.1	82.0
Facilities operations	230.1	256.6	252.4	277.7
University research grants (included in lines above)	(75.2)	NA	(84.2)	(95.5)
Total research and facilities operations	408.2	446.6	439.3	492.8
Capital equipment, including research instrumentation	76.7	77.8	79.8	85.5
Construction, principally at national laboratories				
Accelerator improvement projects	11.2	11.7	11.7	14.9
General plant projects	10.7	11.1	11.1	13.4
Brookhaven AGS accumulator-booster	8.3	14.0	14.0	5.0
Fermilab computer center	11.0	3.6	3.6	—
Fermilab linac upgrade	—	—	—	4.7
Total construction projects	41.2	40.4	40.4	38.0
Total high-energy physics program	526.2	566.8	559.4	616.2
Major facilities (sums included in lines above)				
Fermilab				
Operations	115.5	125.7	122.8	134.5
All research	24.4	24.7	23.0	28.3
Capital equipment and construction	45.8	43.9	41.8	46.4
SLAC				
Operations	73.4	85.7	80.2	92.4
All research	24.6	24.5	25.5	29.9
Capital equipment and construction	23.3	28.0	26.3	30.3
Brookhaven				
Operations	39.3	40.6	41.6	44.0
All research	22.2	22.5	20.3	22.0
Capital equipment and construction	24.6	21.8	25.6	23.9
Other national laboratories and university programs				
Operations	1.9	4.6	7.8	6.8
All research, including theory	106.9	119.7	118.2	135.0
Capital equipment and instrumentation	23.4	20.8	20.8	22.8
Superconducting Super Collider				
Operations R&D	33.0	64.8	82.6	69.0
Capital equipment and instrumentation	—	16.0	16.0	21.0
Construction	—	283.0	—	160.0
Total SSC	33.0	363.0	98.6	250.0
Nuclear physics				
Low energy				
Operations	3.1	3.1	3.1	3.2
Research	10.7	11.8	11.6	12.5
Nuclear data programs at national laboratories	10.9	11.4	11.2	11.6
(National laboratories only, included in lines above)	(16.2)	(16.0)	(15.7)	(16.5)
Medium energy, including LAMPF, Bates and CEBAF				
Operations	50.2	52.5	51.2	56.0
Research	13.1	14.6	14.5	17.7
(National laboratories only, included in lines above)	(73.3)	(74.8)	(74.5)	(82.2)
Heavy ion, including Texas A&M, Yale and U. of Washington				
Operations	35.1	35.4	35.5	36.7
Research	29.6	33.1	32.0	34.8
(National laboratories only, included in lines above)	(55.9)	(58.8)	(57.1)	(63.9)
Nuclear theory				
National laboratories	4.7	4.8	4.8	5.1
Universities	5.8	6.2	6.0	7.6
(Total universities grants, included in lines above)	(40.4)	(NA)	(41.2)	(43.8)
Total research and facilities operations	183.6	193.1	189.9	205.3
Capital equipment, including research instrumentation	17.7	18.5	18.5	20.0
Construction				
Accelerator improvement projects	4.4	4.3	4.0	4.6
General plant projects	1.6	1.7	4.0	4.4
CEBAF	33.5	44.5	44.5	65.0
Total construction projects	41.5	52.5	52.5	74.0

Table III continued.

Basic energy sciences				
Materials science research, including solid state physics	126.0	134.6	136.6	140.5
Chemical sciences	88.2	93.1	91.8	97.6
Advanced energy projects	14.3	14.6	14.5	14.9
Applied mathematical sciences	42.5	43.0	42.7	44.9
Energy biosciences	20.3	20.8	20.6	21.2
Engineering and geosciences	31.4	33.4	33.2	34.1
Total research	327.1	339.6	344.3	358.7
Facilities operations				
National Synchrotron Light Source, Brookhaven	19.6	20.3	19.3	23.0
High Flux Beam Reactor, Brookhaven	10.9	11.5	10.9	15.3
Intense Pulsed Neutron Source, Argonne	5.0	5.4	5.1	6.5
High Flux Isotope Reactor, Oak Ridge	22.8	23.7	23.5	28.4
Stanford Synchrotron Radiation Laboratory	10.3	10.5	10.2	13.4
Los Alamos Neutron Scattering Center	3.0	3.1	4.8	4.5
Combustion Research Facility, Sandia-Livermore	3.5	3.6	3.5	4.5
1–2 GeV Synchrotron Light Source, Berkeley	2.0	2.0	1.9	6.0
6–7 GeV Synchrotron Radiation Source, Argonne	10.0	6.2	5.8	10.5
Total operations	87.1	86.3	85.0	112.0
Capital equipment and instrumentation	31.7	31.7	31.7	37.6
Construction				
Accelerator improvements, general plant projects	7.2	7.2	7.2	10.2
Center for Advanced Materials, Berkeley	7.6	—	—	—
3 GeV SPEAR injector, SLAC	3.0	6.5	6.5	4.5
Los Alamos neutron scattering guide hall	8.5	4.0	4.0	—
1–2 GeV Synchrotron Light Source, Berkeley	18.0	30.0	25.0	26.0
6–7 GeV Synchrotron Radiation Source, Argonne	—	6.0	6.0	40.0
Congressional "pork" other projects	72.6	—	39.6	—
University research support, including coop. centers	18.2	15.8	21.7	36.1
University research instrumentation	4.9	5.0	5.0	5.0
Multiprogram laboratories facilities support	53.6	65.9	55.7	55.0
Magnetic fusion				
Confinement systems	159.6	175.6	174.8	168.2
Applied plasma physics	74.8	78.2	78.2	73.2
Development and technology	55.9	54.1	54.1	56.7
Planning, projects and program direction	5.5	9.6	9.6	9.9
Capital equipment	18.7	21.6	21.6	13.2
Construction, including Compact Ignition Tokomak	16.9	20.9	12.4	28.1
Inertial fusion	159.0	163.8	163.8	168.9
Nuclear directed-energy weapons (for SDI)	152.9	134.1	137.0	145.1
New defense production reactors	20.0	NA	60.0	303.5
Nuclear warhead complex cleanup and modification	378.3	NA	2588.0	3663.0

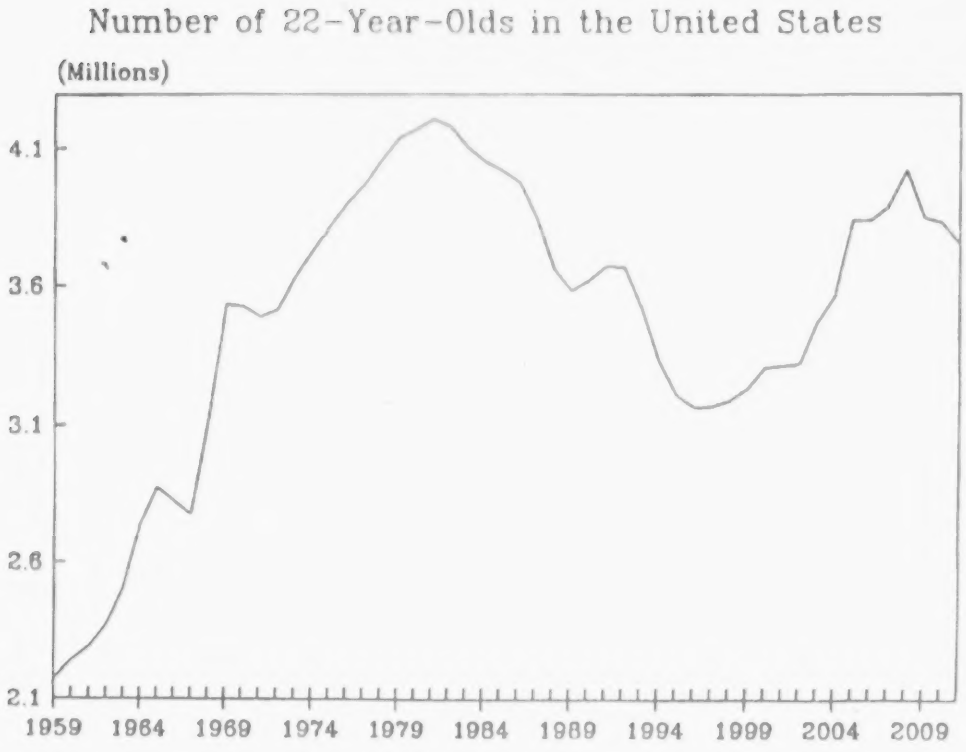
Table IV.

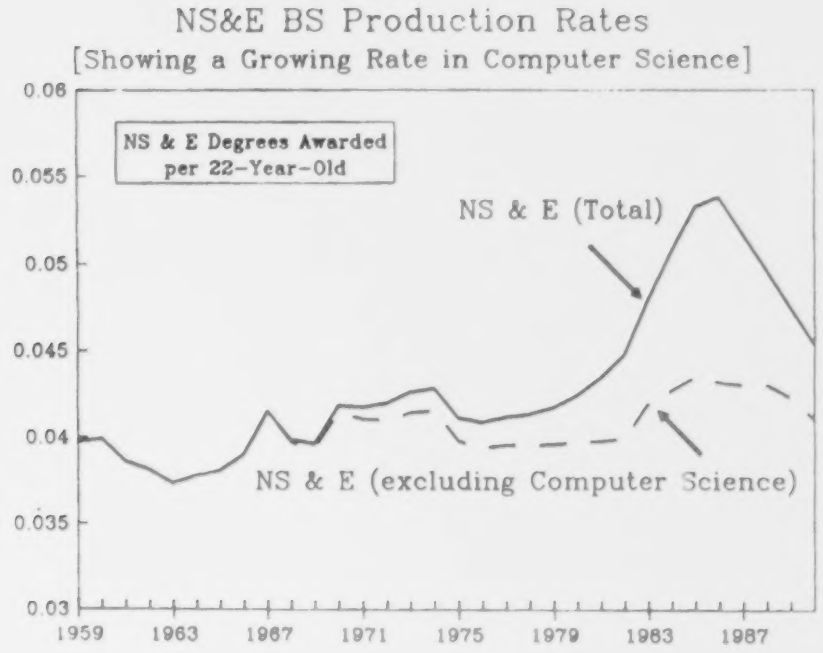
NASA physics-related projects

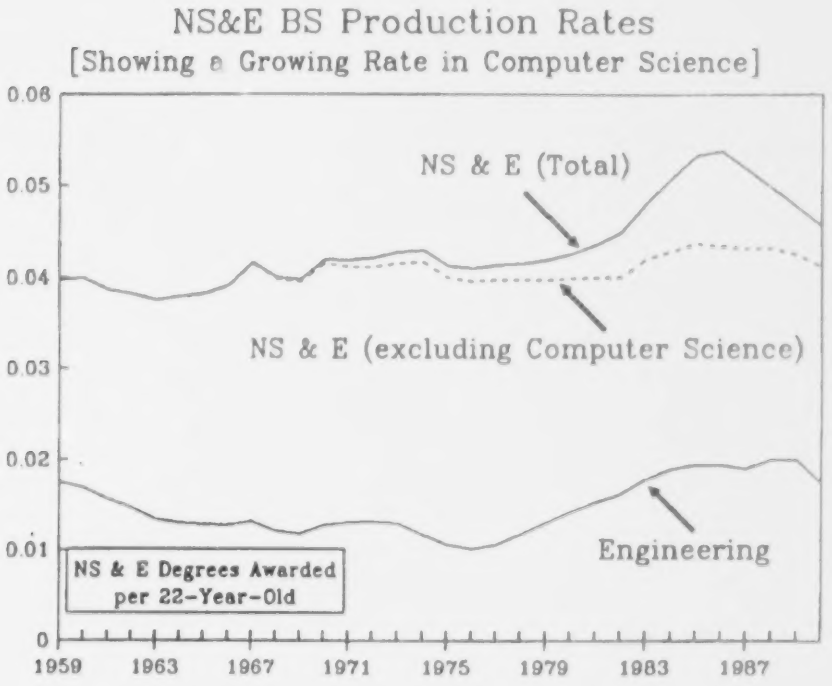
	FY 88 actual	FY 89 request	FY 89 current	FY 90 request
		(millions of dollars)		
Physics and astronomy				
Hubble Space Telescope	93.1	102.2	95.9	67.0
Gamma Ray Observatory development	53.4	41.9	41.9	26.7
Advanced X-ray Astrophysics Facility development	—	27.0	16.0	44.0
Shuttle-Spacelab payload development	47.8	61.5	69.7	86.1
Payload and instrument development	46.6	77.1	81.7	71.4
Space station planning and payloads	18.9	8.0	8.0	23.0
Explorer development	67.9	82.1	82.1	93.2
Mission operations and data analysis	140.5	156.2	143.2	204.8
Research and analysis	82.9	89.1	85.8	112.5
Suborbital programs				
Sounding rockets (includes Spartan)	27.5	28.7	27.0	30.5
Airborne science and applications	7.3	7.8	9.8	10.9
Balloon program	9.9	8.6	8.6	12.1
Global geospace science	18.6	101.4	64.4	112.3
Total physics and astronomy	614.4	791.6	734.1	894.5
Planetary exploration				
Galileo development	51.9	61.3	73.4	17.4
Magellan	73.0	33.9	43.1	—
Ulysses	7.8	10.3	10.3	14.5
Mars Observer	53.9	102.2	102.2	100.5
Comet rendezvous asteroid flyby/Cassini	—	—	—	30.0
Mission operations and data analysis	73.8	112.7	110.7	155.4
Research and analysis	67.3	83.6	76.9	79.1
Total planetary exploration	327.7	404.0	416.6	396.9
Earth science and applications				
Upper atmosphere research satellite	89.2	103.9	94.2	73.9
Ocean Topography Experiment (TOPEX)	74.5	97.8	83.0	72.8
Scatterometer	22.6	15.8	10.6	13.8
Earth science payload instrument development	27.7	45.0	46.4	66.5
Mission operations and data analysis	14.7	18.5	17.6	24.8
Interdisciplinary research and analysis	1.1	1.2	2.2	2.3
Upper atmosphere research and analysis	32.7	34.0	31.1	38.1
Ocean processes research and analysis	20.1	21.6	20.8	24.5
Atmospheric dynamics research and analysis	31.4	32.8	32.0	37.4
Land processes research and analysis	21.1	22.9	19.9	22.5
Geodynamics	32.3	33.9	32.9	38.0
Airborne science and applications	21.8	23.0	23.0	19.7
Total earth science and applications	389.2	450.4	413.7	434.3
Materials processing in space				
Microgravity shuttle-space station payloads	49.8	59.8	56.4	74.6
Commercial microgravity R&D enhancements	—	—	5.6	5.1
Research and analysis	12.9	13.6	13.6	13.0
Total materials processing	62.7	73.4	75.6	92.7
Other physics-related projects				
Research and technology base				
Fluid and thermal physics research	33.9	38.0	43.7	44.0
Materials and structures research	55.7	57.6	60.1	62.1
Information and computer sciences	26.6	32.0	17.3	19.2
University space research	4.0	16.3	16.3	17.1
Space research and technology				
Pathfinder program	—	100.0	40.0	47.3
Civil space technology initiative	114.2	156.8	121.8	144.5
In-space experiments technology	—	—	—	16.2
Space Station Freedom program	392.3	967.4	900.0	2050.2

Graduate Programs in Science and Engineering

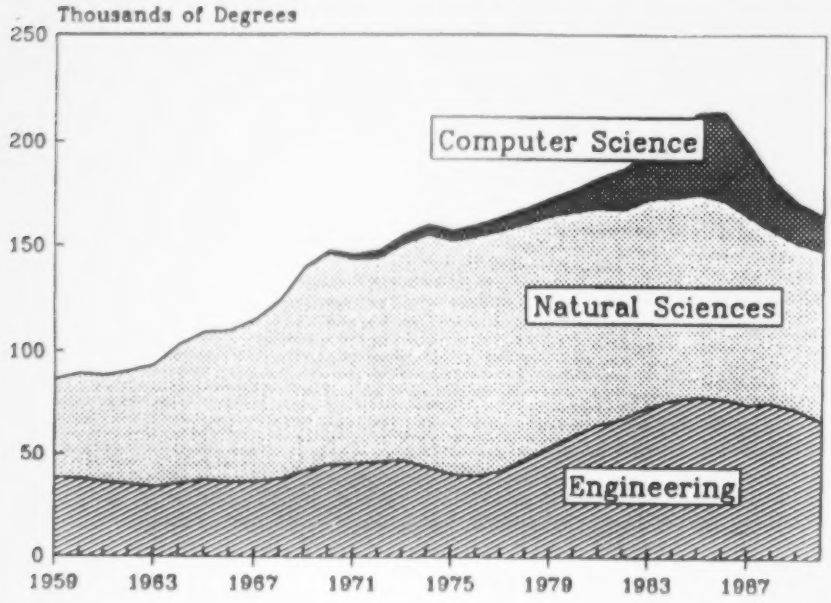
Bassam Shakhashiri
National Science Foundation



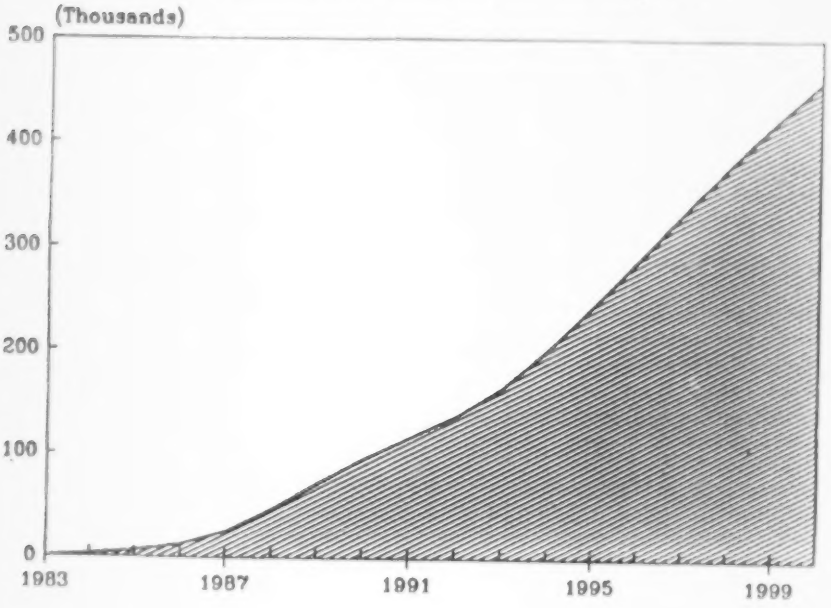

NS&E BS Production Rates
[Showing a Growing Rate in Computer Science]
0.06
0.055
0.05
0.045
0.04
0.035
0.03
NS & E Degrees Awarded
per 22-Year-Old
NS & E (Total)
NS & E (excluding Computer Science)
1959
1963
1967
1971
1975
1979
1983
1987


NS&E BS Production Rates
[Showing a Growing Rate in Computer Science]
0.06
0.05
0.04
0.03
0.02
0.01
0
NS & E (Total)
NS & E (excluding Computer Science)
Engineering
NS & E Degrees Awarded
per 22-Year-Old
1959
1963
1967
1971
1975
1979
1983
1987

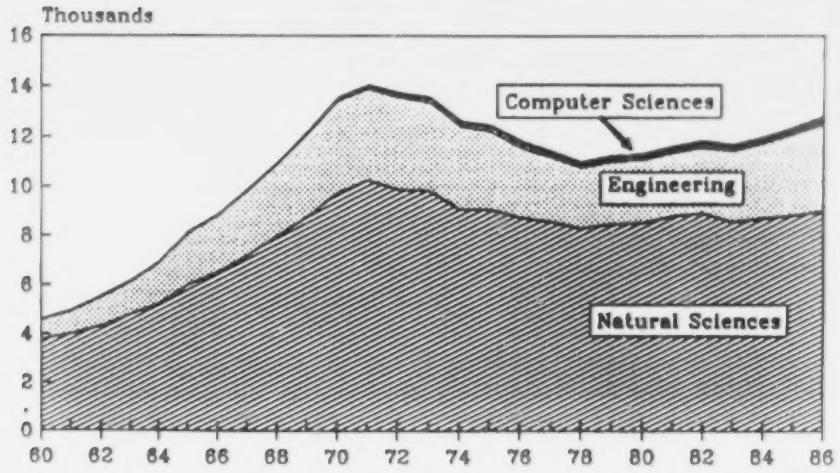
NS&E BS Production
[Showing Expected Effects of Freshman Intentions]



NS&E Cumulative Shortfalls: BS Degrees

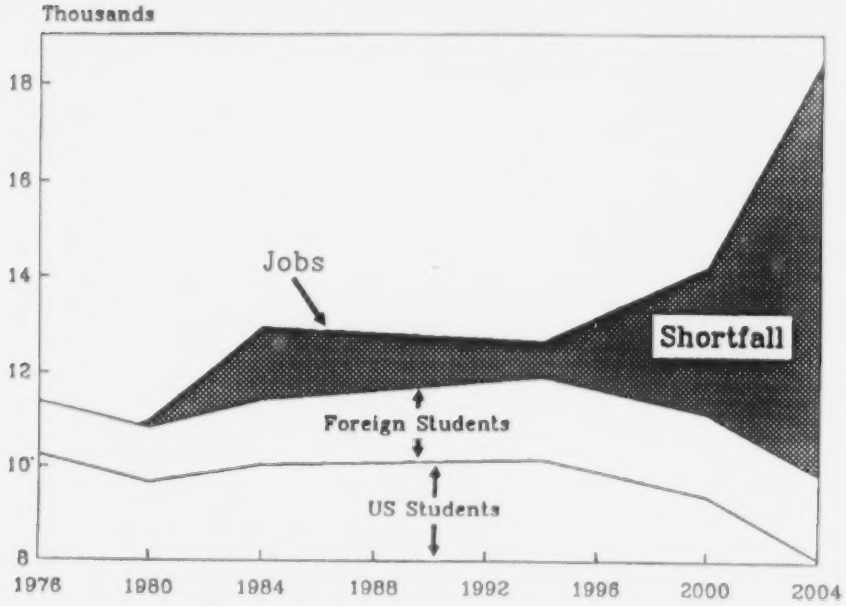


PhD Degrees in Natural Science and Engineering

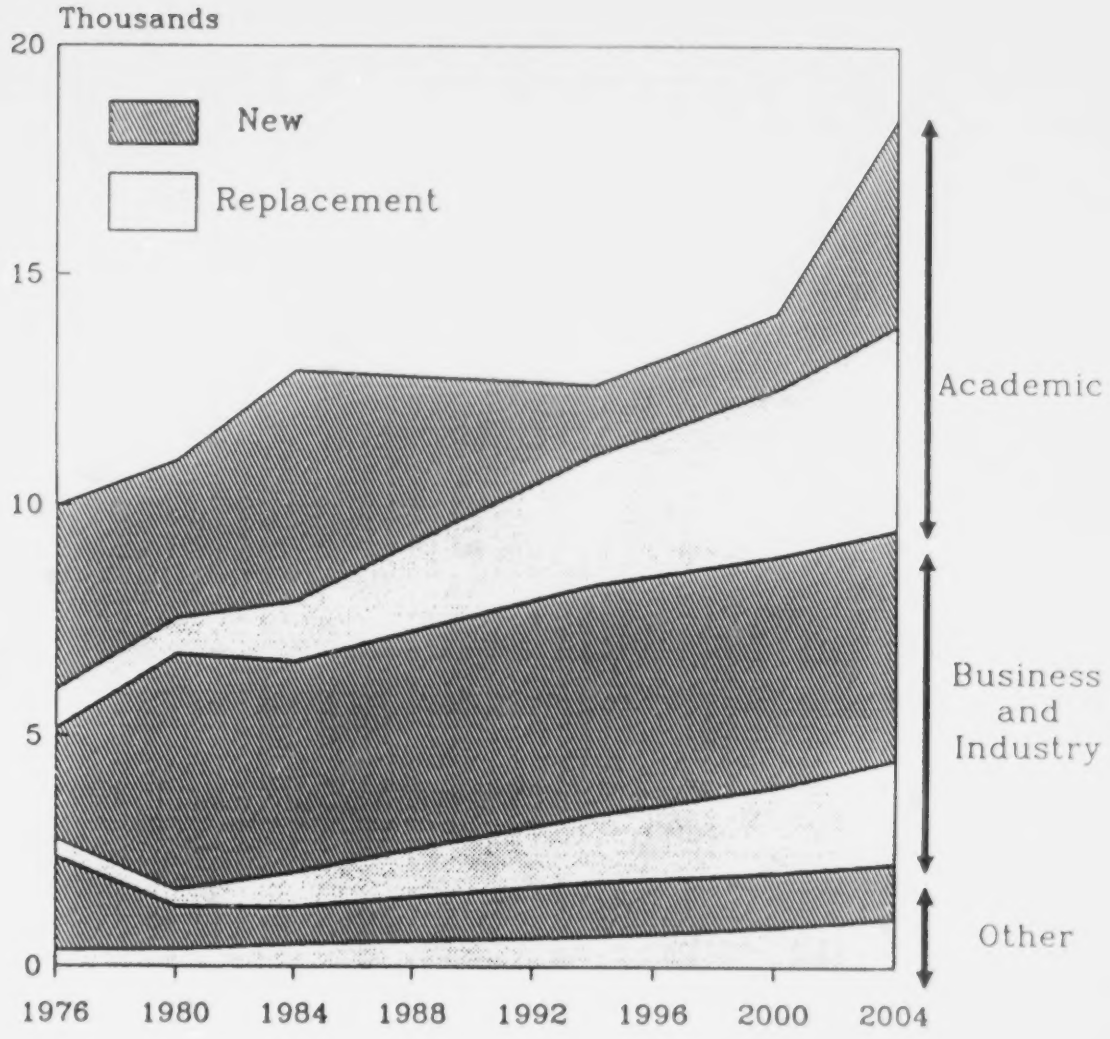


Average Annual Production of Ph.D.s

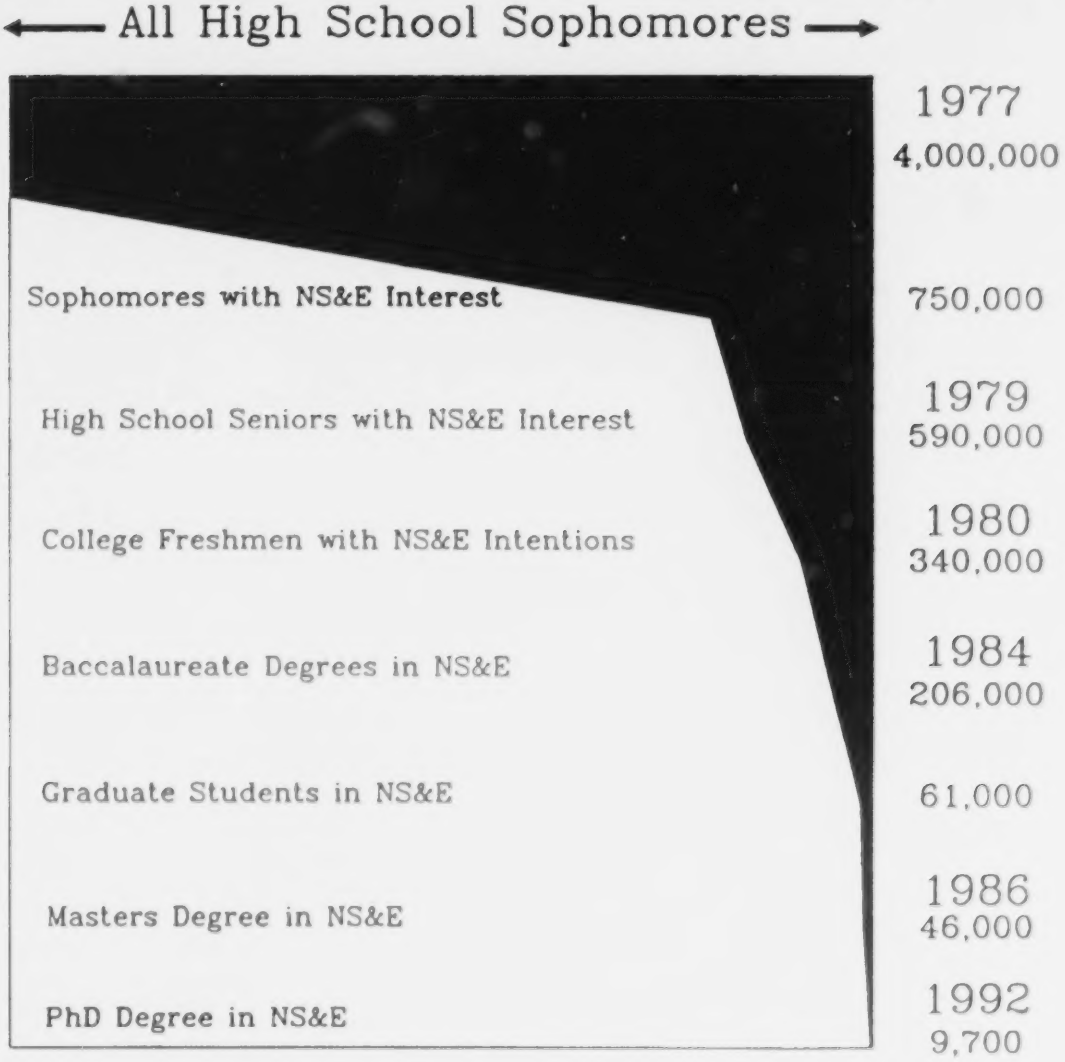
NS & E Ph.D. Degrees from U.S. Institutions



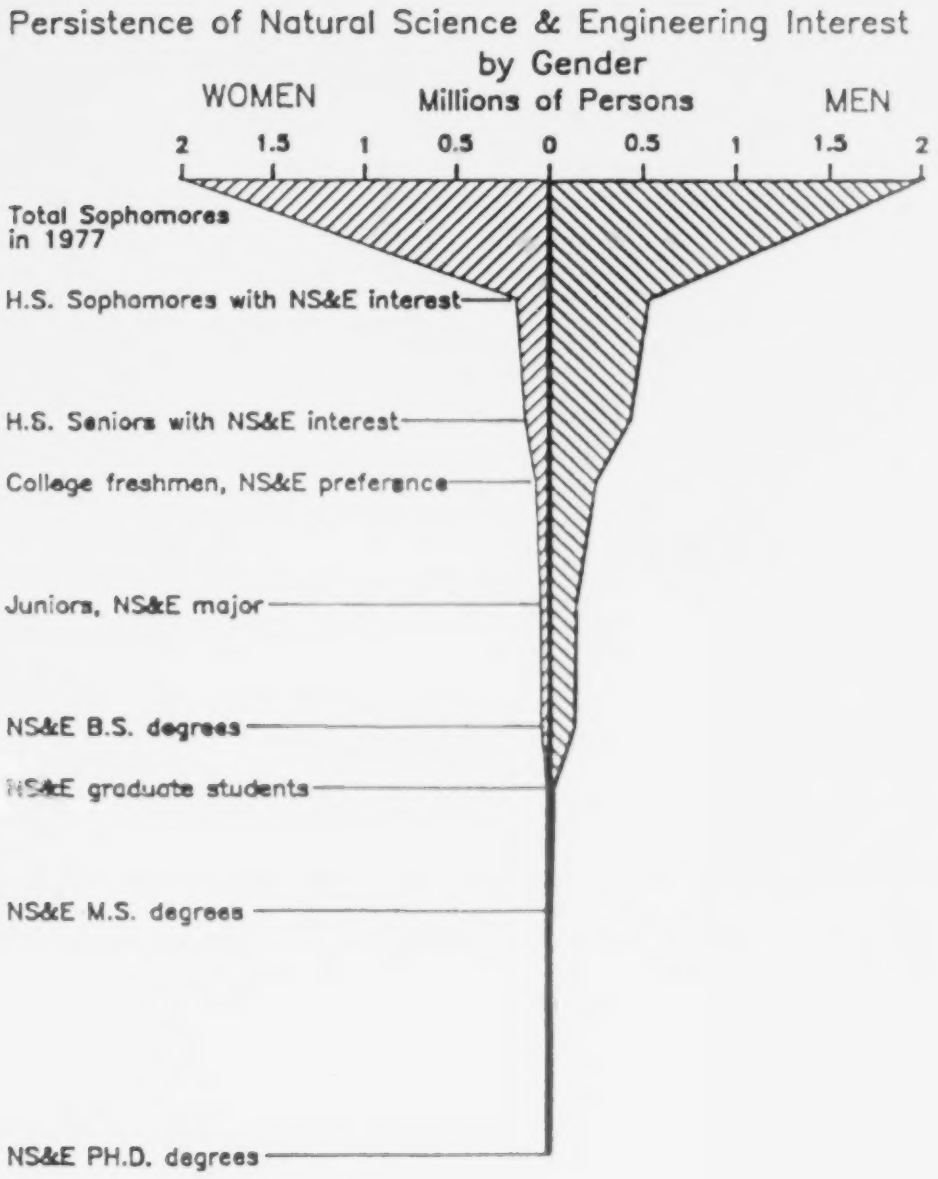
Available PhD Positions for Natural Scientists and Engineers

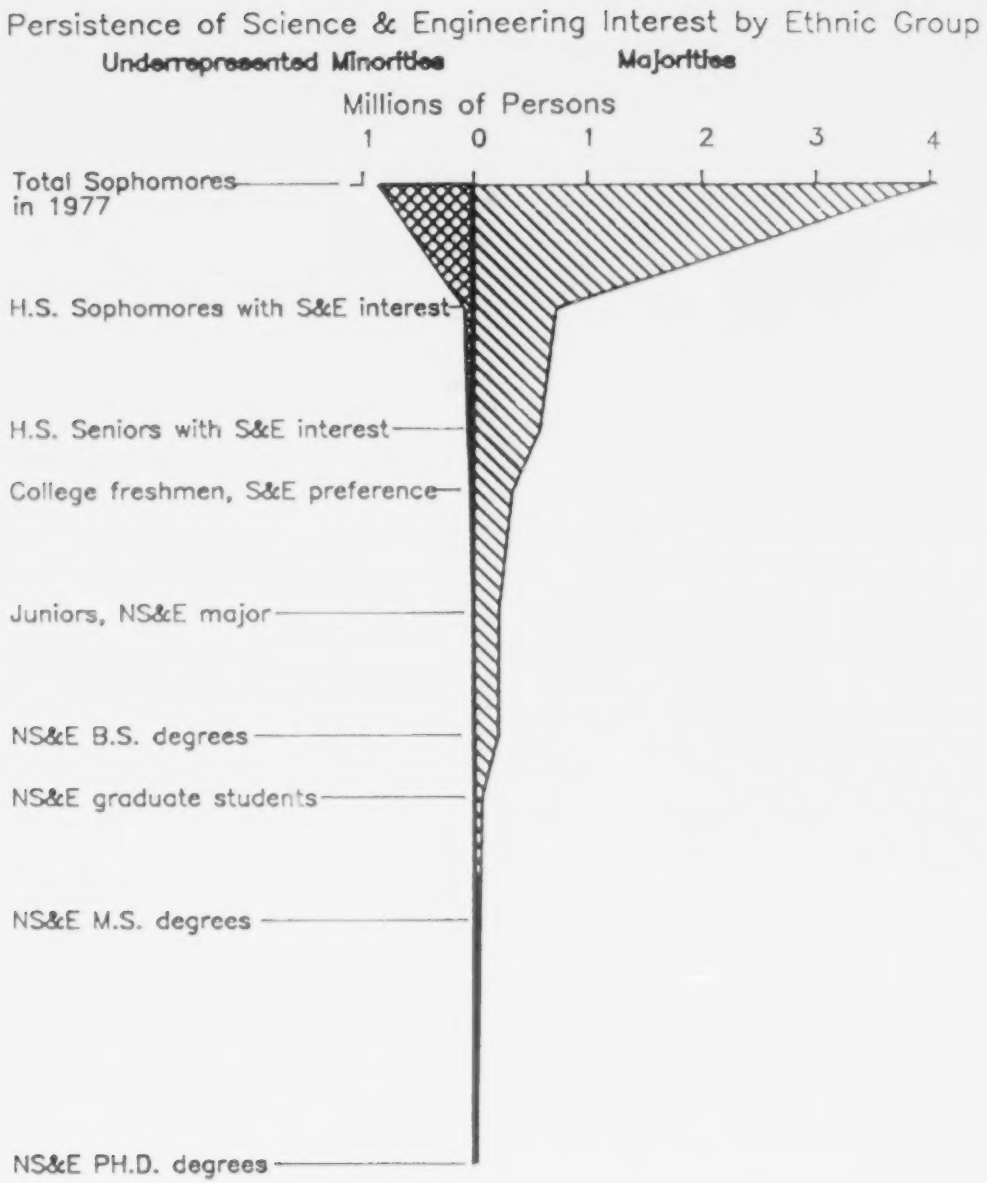


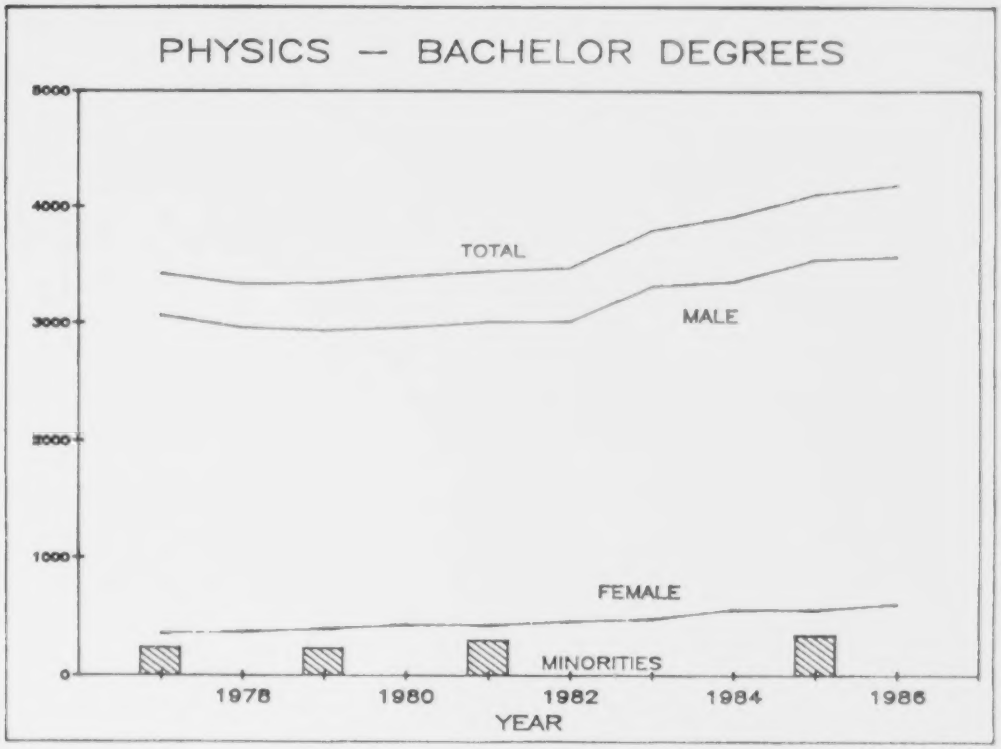
Persistence of NS&E Interest from High School through PhD Degree

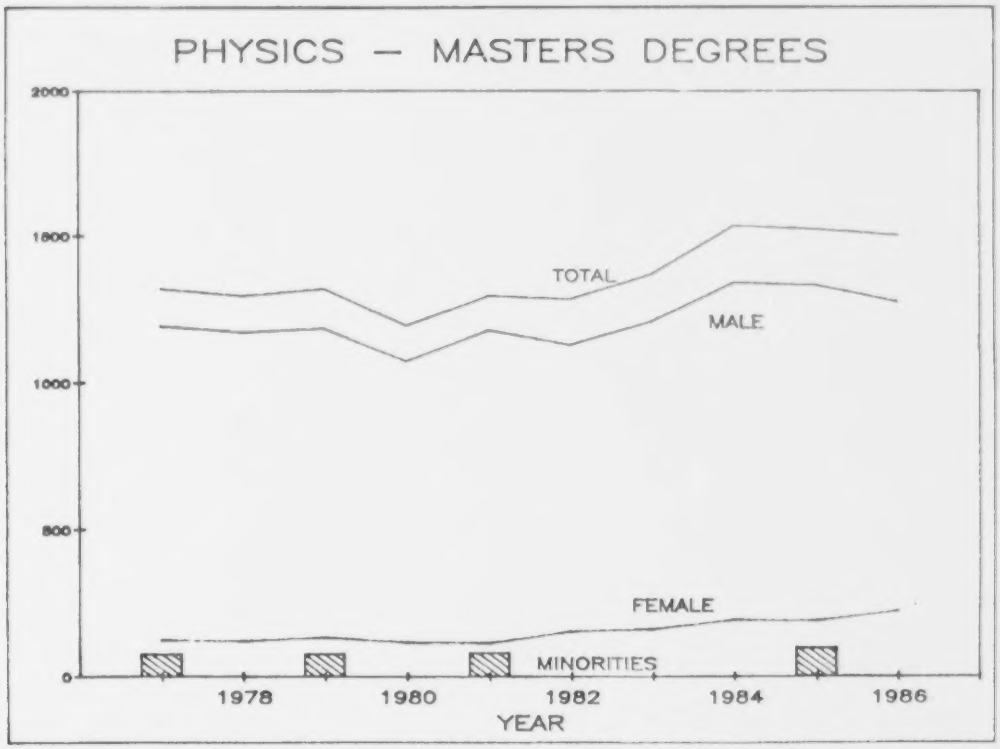


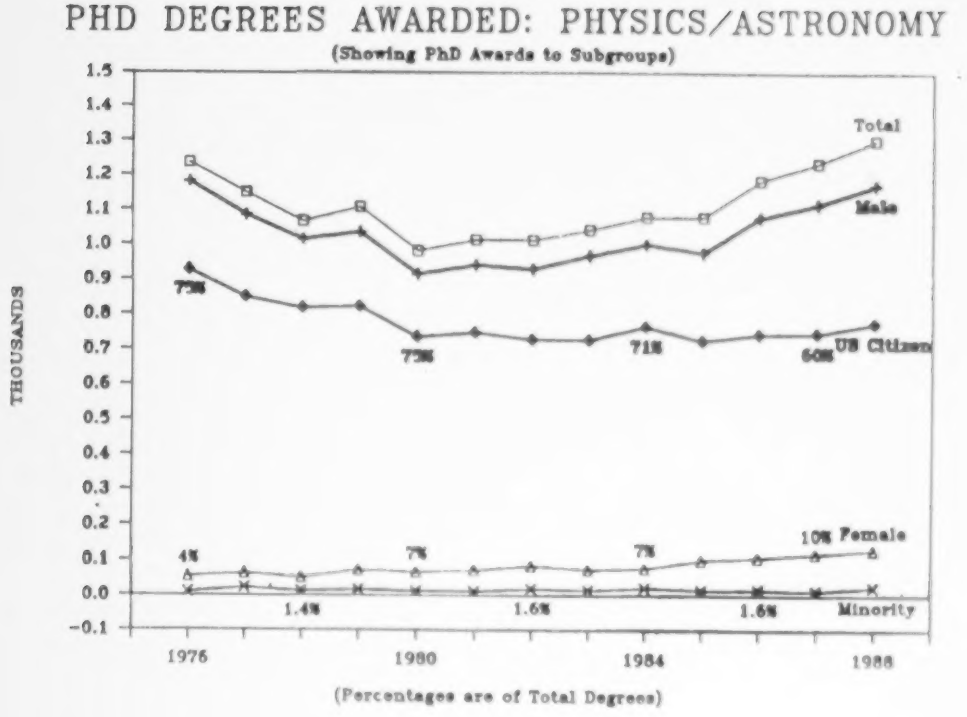
(The Pipeline)

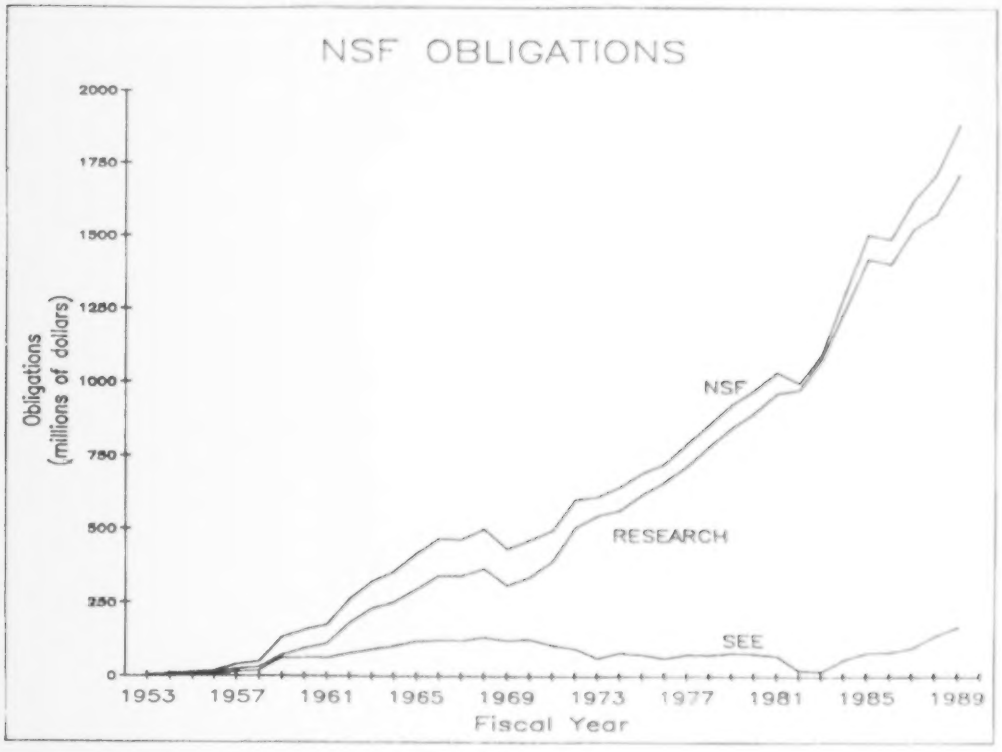

Persistence of Natural Science & Engineering Interest
by Gender
WOMEN
Millions of Persons
MEN
2
1.5
1
0.5
0
0.5
1
1.5
2
Total Sophomores in 1977
H.S. Sophomores with NS&E interest
H.S. Seniors with NS&E interest
College freshmen, NS&E preferance
Juniors, NS&E major
NS&E B.S. degrees
NS&E graduate students
NS&E M.S. degrees
NS&E PH.D. degrees


Persistence of Science & Engineering Interest by Ethnic Group
Underrepresented Minorities
Majorities
Millions of Persons
1
0
1
2
3
4
Total Sophomores in 1977
H.S. Sophomores with S&E interest
H.S. Seniors with S&E interest
College freshmen, S&E preference
Juniors, NS&E major
NS&E B.S. degrees
NS&E graduate students
NS&E M.S. degrees
NS&E PH.D. degrees

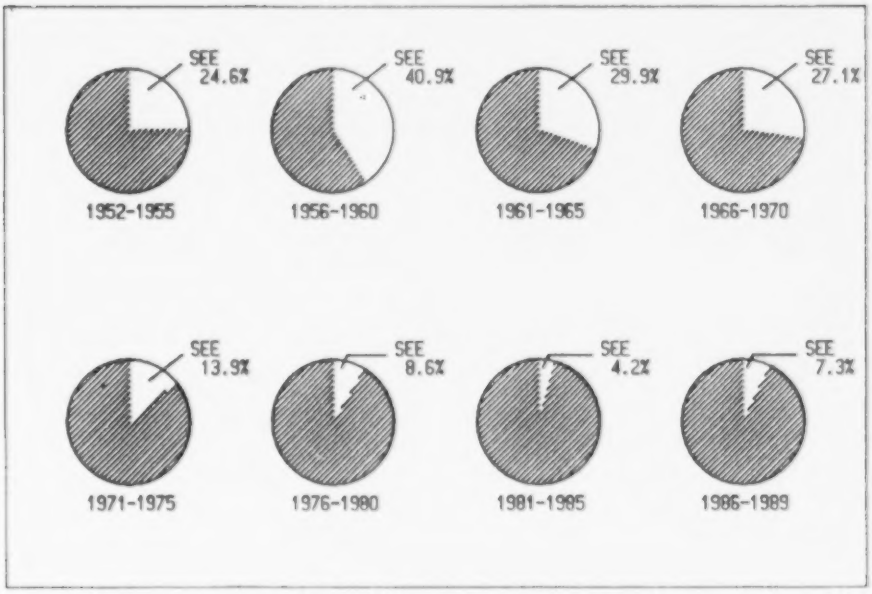

PHYSICS — BACHELOR DEGREES
5000
4000
3000
2000
1000
0
TOTAL
MALE
FEMALE
MINORITIES
1978
1980
1982
1984
1986
YEAR

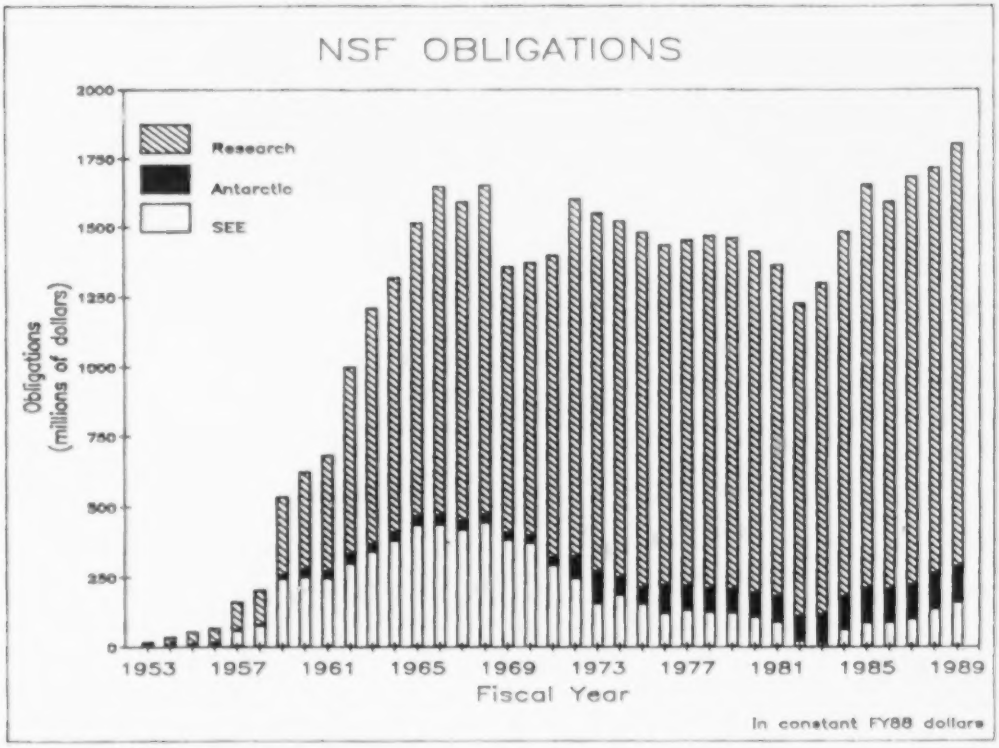

PHYSICS — MASTERS DEGREES
2000
1800
1000
800
0
TOTAL
MALE
FEMALE
MINORITIES
1978
1980
1982
1984
1986
YEAR


PHD DEGREES AWARDED: PHYSICS/ASTRONOMY
(Showing PhD Awards to Subgroups)
THOUSANDS
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
Total
Male
US Citizen
Female
Minority
72%
73%
71%
60%
4%
7%
7%
10%
1.4%
1.6%
1.8%
1976
1980
1984
1988
(Percentages are of Total Degrees)

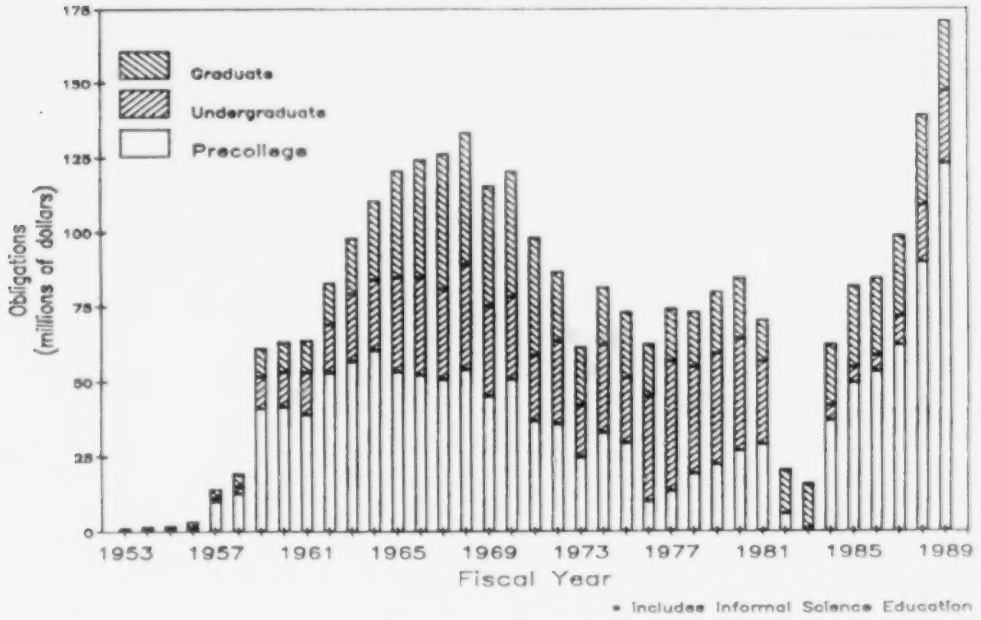

NSF OBLIGATIONS
Obligations
(millions of dollars)
2000
1750
1500
1250
1000
750
500
250
0
NSF
RESEARCH
SEE
1953
1957
1961
1965
1969
1973
1977
1981
1985
1989
Fiscal Year

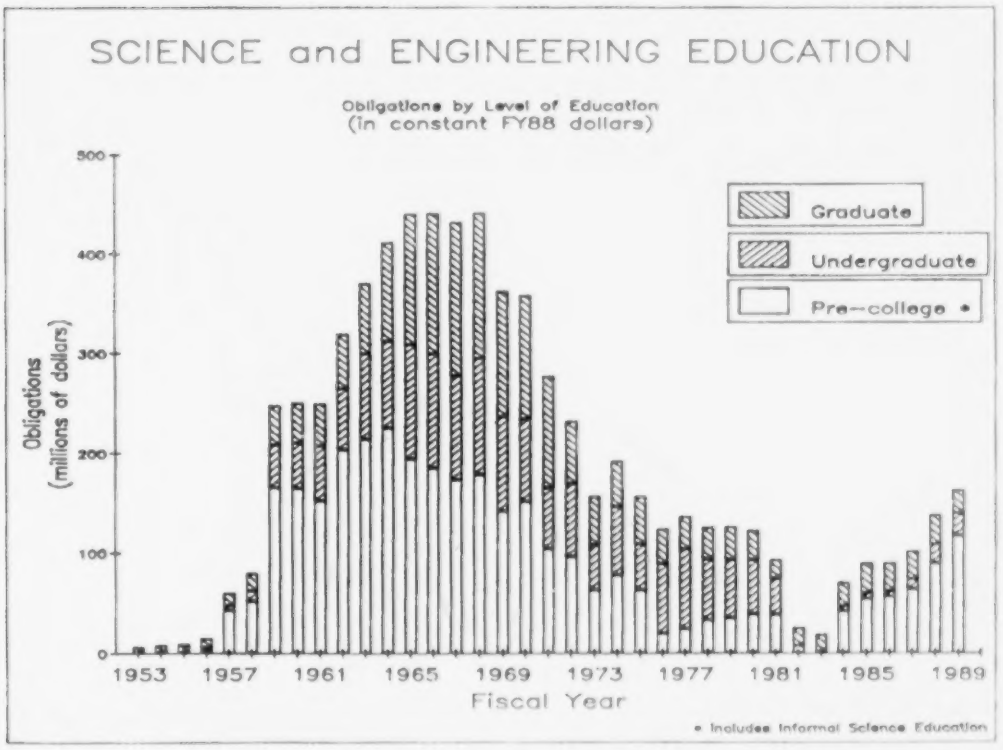
Obligations for Science & Engineering Education
as percent of NSF Budget





NSF Science and Engineering Education Obligations
by Level of Education
(in current year dollars)





Physics in the NSF Division of Materials Research

A.I. Schindler
National Science Foundation

NSF Division of Materials Research Budget

PROGRAM ELEMENT	FY87	FY88	FY89	FY90 Request
Solid State Physics	$ 11.78 M	$ 11.65 M	$ 11.98 M	$ 12.85 M
Solid State Chemistry	8.53	8.58	8.81	9.42
Low Temperature Physics	7.96	8.22	8.68	9.28
Condensed Matter Theory	8.66	8.84	9.34	10.38
Metallurgy	9.51	9.03	9.34	9.96
Ceramics & Elect. Mat.	6.43	8.14	8.29	9.06
Polymers	7.03	7.95	8.16	8.66
M.R.L.'s	26.55	26.17	26.19	27.09
M.R.G.'s	6.03	7.38	8.07	9.11
National Facilities	11.20	10.62	12.13	24.63
Instrumentation	4.90	3.97	3.99	4.74
Total	$108.58 M	$110.56 M	$114.98 M	$135.18 M
SCIENCE & TECH. CENTERS	--	--	$ 10.22 M	

APPROXIMATE NUMBER OF PHYSICISTS SUPPORTED BY DMR (1988 DATA)

DMR ORG.	SENIOR PERSONNEL	GRADUATE STUDENTS	POST DOCS	TOTAL AWD. AMOUNT
SSP	148	230	37	$ 11.65 M
LTP	90	161	33	8.22
CMT	118	131	70	8.84
SSC	19	35	10	1.78
TOTAL	375	557	150	$ 30.49 M
MET	13	17	0	$ 0.60 M
CEM	14	21	1	0.89
POL	5	9	1	0.36
TOTAL	32	47	2	$ 1.85 M
MRL	101	114	27	$ 7.72 M
MRG	39	29	7	2.63
TOTAL	140	143	34	$ 10.35 M

Physics in the Department of Energy

John O'Fallon
Department of Energy

DOE Division of High Energy Physics: Support of Science Education

- The Division of High Energy Physics provides approximately 90 percent of the federal support for high energy physics research, and about two-thirds of the university funding for high energy physics.
- Most of the DOE-supported high energy physics research is performed at its three major accelerator facilities, all of which are user facilities – Fermi National Accelerator Laboratory, Stanford Linear Accelerator Center, and the alternating gradient synchrotron at Brookhaven National Laboratory.
- The Division supports over 1700 physicists and 800 students at about 100 universities. These university scientists perform over 75 percent of the DOE-supported high energy physics research.
- The Outstanding Junior Investigator (OJI) program has been instrumental in establishing new scientists in the high energy physics area. Approximately one-third of the DOE's recently established high energy physics researchers received their initial, independent funding from the OJI program. Eight OJI awards were made in 1988.

Major New Initiative for FY 1990

- The university programs in the Division of High Energy Physics continue to be a vigorous and essential part of the national high energy physics program.
- University involvement is shifting from the university campus to the accelerator laboratories.
- There is a corresponding decline in the technical support base at the universities.
- In response to this need, a major new initiative to enhance the technical support capabilities at universities has been proposed by DOE. Five million dollars per year starting in FY 1990 has been requested for this effort.
- This initiative is aimed at upgrading instrumentation and research facilities and rebuilding technical support staff at universities supported by the Division of High Energy Physics.

Other DOE Education Programs

In FY 1989, approximately $12 million will be provided through specific programs to undergraduate and precollege education. An additional $13 million will be provided to historically black colleges and universities and other minority institutions.

Undergraduate education attempts to attract students at this level so that they will pursue science and engineering graduate programs. This is done through research internships at DOE laboratories, science and engineering research semesters, and historically black college and university programs.

Precollege programs are aimed at enhancing the general scientific literacy and knowledge base of all students and targeting those with potential for continued scientific and engineering education. This is done through minority student research apprenticeships, DOE high school honors research program, prefreshmen engineering program, precollege science teacher research/training, and laboratory technical assistance to precollege schools.

Interacting with the Federal Government

Congressman Mike McCormack

Probably more than half of today's federal and state legislation relates in some significant way to science or technology. Yet there is an alarming dearth on meaningful communication across the gulf of mutual ignorance and suspicion that separates the scientific and political worlds. Scientists are more aware of this problem and its implications than are their political counterparts.

It is essential for members of the scientific community to reach out to public officials, remembering that caricatures of corrupt politicians are no more accurate than caricatures of mad scientists. Most elected officials must function under extreme pressures from heavy workloads, the continual need to raise campaign funds for biennial elections, and a news media that prefers to feature extremists and demagogues than thoughtful public officials seeking informed and reasonable solutions to societal problems.

Scientists and engineers probably can be most effective in helping their congressmen understand proposed legislation involving science and technology, and the important issues related to it, by creating small constituent committees to meet with the congressman in his or her home district in a quiet setting away from phones and other distractions. This should be a regular event, every three or four months, and scientists should always be available to assist the congressman in obtaining accurate information relative to any technical issue, and assistance in considering its merits. Individual committee members who believe that a congressman should be reelected should accept their role as responsible citizens, contributing generously of time and money to the congressman's campaign.

A PALLADIUM CURTAIN DESCENDS OVER UTAH

Robert L. Park

Good evening. It is an honor to be invited to participate in this conference. Specifically, I was asked to bring you all up to date on what is surely the most significant scientific controversy since the claim that monoxidil can reverse baldness. I assure you that the events I will relate, however improbable they may seem, are to the best of my knowledge true. There is no need to make things up.

We are all acutely aware that two thousand miles away there is another meeting going on. More than a thousand scientists from every corner of the earth are gathered in Santa Fe, New Mexico, to exchange theoretical and experimental evidence relevant to the question of whether deuterium nuclei can be made to fuse by squeezing them together in a palladium lattice. Many thousands of other scientists are watching the proceedings live via satellite.

Stanley Pons and Martin Fleischmann, the temperamental stars who started all this, were given top billing in the preliminary program for the show in Santa Fe. I must report, however, that they cancelled their appearance. But don't judge them too harshly. Their withdrawal was regrettable, but there were extenuating circumstances. Two weeks ago in Los Angeles they had announced that they were undertaking a new test, free of the flaws that marred their previous work. The results, they said, would persuade the most cynical skeptic of the validity of their breakthrough. That was the work they had expected to present in Santa Fe.

Alas, fate dealt them a cruel setback. Last week a raccoon wandered into a transformer on the Utah campus. Delicacy prevents me from giving you a detailed report on the condition of the raccoon (particularly insofar as you are still digesting dinner), but electrical power to the chemistry building was temporarily interrupted. During the outage, deuterium, which had been loaded into the palladium cathode of their electrolysis cell over a period of several days, diffused back out, forcing them to start all over.

It was all the more awkward for them because they had been forced to cancel an appearance before many of the same scientists on May 1. On that occasion, the Spring Meeting of the American Physical Society in Baltimore, they were just too busy preparing for a congressional visit to their laboratory to attend. Sen. Jake Garn (R-UT) had arranged for an Air Force transport to carry a load of Washington dignitaries to Salt Lake City for a first-hand look at cold fusion. Garn, of course, had already been to outer space as guest astronaut on the shuttle, so he was a natural host for this trip. After the Baltimore APS meeting, however, not even the Senate custodial staff seemed interested in a demonstration of cold fusion, and the trip was cancelled.

Interestingly enough, Pons did manage to be in Washington during the APS Meeting, just 40 miles from Baltimore. He was there to meet with White House Chief of Staff John Sununu and possibly President Bush, but after the papers reported on the first cold fusion session in Baltimore, Sununu stood him up.

But I am way ahead of myself. Let us begin two full moons ago, on the 23rd of March. The sun warmed the earth that day the old-fashioned way, by high temperature fusion of hydrogen nuclei. It has been doing that for nearly five

billion years and has a long way to go. Which is to say that even under the extreme conditions of the sun's interior, old-fashioned fusion is a rather slow process--which is a good thing for us.

The University of Utah held a press conference that day to announce that Pons and Fleischmann had discovered a new way to fuse deuterium nuclei, without extreme temperatures--a sort of "latterday fusion." Actually, the story had already been broken by the Financial Times of London and the Wall Street Journal. They had received advance notice, which may give you some clue as to what this thing is all about.

If Pons and Fleischmann were right, their discovery could liberate the earth from its nightmare of slow strangulation in the excrement of its own energy production. It could spawn an industry larger than any ever seen, and its creators would be showered with honors. If they were right.

The information given to the press, unfortunately, was devoid of any details that might enable other scientists to judge the strength of the Utah claim--and they were speaking only to the press. This was no mere breech of etiquette. The integrity of science depends on one inviolate rule: each new advance must be exposed to the scrutiny of skeptical colleagues. That rule had just been broken--a palladium curtain had descended over Utah--and the stakes were high.

Of course the stakes were also high on September 17, 1926, when the first press conference to announce hydrogen fusion in palladium was held in Berlin. According to news accounts from the time:

Profs. F. Paneth and K. Peters describe how they have succeeded in detecting the presence of minute amounts of helium derived from hydrogen which had been absorbed by finely divided palladium at ordinary temperature. This announcement, if correct, is of great importance and will evoke even more interest than the claim by Miethe and Stammreich to have transmuted mercury into gold.

I have not been able to track down the Miethe and Stammreich paper, but alchemy may be due for a comeback. Whatever goes around comes around, they say. (I was never quite clear about what that means, but it may apply here.)

Back to the present. Within hours of the Utah announcement, scientists in dozens of laboratories were clustered around blackboards to discuss the fragmented information that trickled down from the press. The first step was to ask whether the Utah experiment violated accepted physical principles that have in the past served as a reliable guide. Could the deuterium nuclei come close enough together in a Palladium lattice to tunnel through the Coulomb barrier and fuse? The calculations didn't look at all promising, but science is interesting precisely because it keeps surprising us. Perhaps there is some miraculous screening in Pd that allows an unexpectedly close separation!

Alas, there was a more troubling problem: deuterium fusion produces neutrons. If this reckless pair had produced as much fusion as they claimed, why didn't they glow in the dark? The Utah scientists said this simply meant that in Pd, for some unexplained reason, deuterium nuclei prefer to fuse by an otherwise unlikely route that results in the production of He-4 and no neutron. If you bought the last miracle, why not this one too?

However, this still didn't explain the apparent robust health of the two electrochemists. If fusion resulted in the production of the He-4, nucleus there should be a whopping 23 MeV gamma ray. Not to worry! By some miraculous process it seems that the excess energy is coherently absorbed by the entire Pd lattice, thus producing only heat.

Stop! One miracle is exciting. Two might persuade me to change my religion, but three is too many even in Salt Lake City.

Of course, there is a sub-discipline of theorists that thrive on the challenge of explaining every observation. They can be identified by the fact that they succeed equally well when the observations are in error. One theorist at MIT stayed up all night and produced four manuscripts explaining all three cold fusion miracles plus a couple more which haven't been reported yet. The papers were submitted to Physical Review Letters, and the provost of MIT called a press conference to announce that MIT had filed patents on the work. The press delighted in describing the theorist as "the brooding genius who invented the X-ray laser." What X-ray laser? In spite of having inspired President Reagan's Star Wars program, it is not clear that there has been enough lazing to take a decent chest X-ray.

I digress. It was clear that the Pons and Fleischmann experiment would have to be replicated, but how could this be done if they refused to reveal the details? Overnight, an informal intelligence network took form. A computer bulletin board was set up to share information among laboratories all over the world. FAX machines were used to share press clippings, since different reporters had included different details in their stories. Video tapes of interviews with Pons and Fleischmann were played over and over. Press photographs were blown up to get a closer look at the Utah apparatus. The width of Pons wrist was used to estimate dimensions. Why, I was repeatedly asked by the press, if most scientists are skeptical, are they all doing the experiment? A partial answer is that the cheers are just as loud when you sack the other team's quarterback as when you throw a touchdown.

Initial reports looked good for Utah. Encouraged by talk of supporting theories, a number of laboratories rushed to report partial confirmation. These initial "Elvis sightings" would be withdrawn one by one in the coming days as mistakes turned up.
When groups tentatively reported they hadn't seen anything yet, Pons and Fleischmann explained that it took several days to "load the cathode" with deuterium before the reaction could begin. When they still saw nothing after a week, the Utah scientists said sometimes it takes two or three weeks, or the cathode was the wrong size; or they had the wrong electrolyte, or it only worked with cast palladium and not with extruded.

Matters were further confused by the report from Brigham Young of neutrons. The press, not fully appreciating what a difference of thirteen orders of magnitude meant, reported this as a partial confirmation of Pons and Fleischmann. Similarly, when a group at a national laboratory acknowledged to a reporter that they detected neutrons "but the number was not statistically significant," it came out in the papers as "they see a small effect."

Thus it was that at the American Chemical Society meeting in Dallas on April 12, a crowd of 7,000 chemists gave Pons a standing ovation. But there were already ripples on the surface to warn the cautious that danger lurked below. Pons was asked what happens if ordinary water is substituted for the heavy water. This basic control, it turned out, had never been performed!

Pons returned to Utah eager to perform the light water control. A week later, however, his only comment was, "we did not get the baseline we expected." Translation: it behaves about the same with plain water. Pons and Fleischmann had now performed the definitive control, but instead of the obvious conclusion that it was not fusion they were observing, they now apparently invoked a fourth miracle--even ordinary hydrogen can be made to fuse! If you swallow enough miracles, you begin to develop a tolerance.

Out of sight of the public, the wheels were beginning to come off. Those laboratories best equipped to test the Utah claim were finding nothing remarkable, but no one calls a press conference to announce a negative result. So back in Utah, hundreds of private companies were clamoring for a piece of the action. The Utah legislature met in special session to vote the University $5 million dollars to get started on exploiting the discovery. In Washington, the Strategic Defense Initiative was organizing a workshop to see if cold fusion could power a space-based missile defense. James Fletcher, the retiring head of NASA and a former president of the University of Utah agreed to head a committee overseeing the Utah cold fusion research effort. At Lawrence Livermore Laboratory, Edward Teller gave cold fusion his blessing. His protege, Lowell Wood, anxious to prove his mentor was right again, rushed to repeat the Utah experiment. Unfortunately, the deuterium liberated by electrolysis collected in the laboratory and abruptly exploded--the old-fashioned chemical kind of explosion-- destroying his laboratory.

On April 26, cold fusion was given a full hearing before the Science, Space and Technology Committee of the House. The President of the University of Utah, Chase Peterson, was one of those testifying. He had risen to the presidency from directorship of public information at the University by virtue of his deft handling of the publicity surrounding the Jarvik Heart. You may recall the tragic figure of Barney Clark. When asked how much money Utah needed for cold fusion, Peterson smiled and said, "the figure of $25 million comes to mind." One admiring congressman said, "It's the least we can do." The hearing was stage-managed by Gerald Cassidy, the high-priced Washington lobbyist who invented the post-industrial pork barrel. A "business strategy consultant" also testified for the University. He urged Congress not to "dawdle around" waiting for confirmation or the Japanese would beat us to commercialization.

That was the zenith for cold fusion. Five days later the American Physical Society held its special session on cold fusion at the Spring Meeting in Baltimore. You all know what happened. The corpse of cold fusion will continue to twitch for awhile. "Elvis sightings" will gradually dwindle, a few remaining puzzles will be found to have unremarkable explanations, additional sources of error will be tracked down, someday perhaps we will learn the results of the helium analysis experiments on the Utah cathodes.

Its demise was mercifully swift. It is not always so. After an exhaustive three-year study of parapsychology, a panel of the National Academy of Sciences solemnly reported just last year that: "The committee finds no evidence from

research conducted over a period of 130 years for the existence of parapsychological phenomena." None! In 130 years! Nevertheless the true believers will go right on collecting mountains of statistics to find the one result that will confound the skeptics, and Hollywood will go right on making money. "Polywater," with hundreds of scientists working on it, lasted nearly four years. When a magnetic monopole was spotted passing through Palo Alto a few years ago, it triggered a flurry of activity that went on for about a year.

Let me read a passage from a wonderful paper by the great chemist, Irving Langmuir, entitled "Pathological Science."

The Davis-Barnes effect and the N-rays and the mitogenetic rays, have certain things in common. These are cases where there is no dishonesty involved but where people are tricked into false results by a lack of understanding about what human beings can do to themselves in the way of being led astray by subjective effects, wishful thinking or threshold interactions. These are examples of pathological science. They have attracted a great deal of attention. Hundreds of Papers have been published on them. Sometimes they have lasted for fifteen or twenty years and then they gradually die away.

I am going to miss cold fusion. It was a wonderful object lesson for students on why established procedures should be adhered to and why science flourishes only in the open. The lesson may not have been learned by those who most need it, however. The palladium curtain over Utah is still intact. Plans to invite a Brookhaven scientist to give a talk at the University of Utah this week were cancelled when Pons objected. The Brookhaven scientist, an electrochemist, is a coauthor of an invited paper being given in Santa Fe that will report no evidence of fusion. University lawyers supported the decision, arguing that Pons might feel pressured to defend himself by revealing the "secret formula." Dreams die slowly.

And the public is not inclined to thank those who shatter dreams. Beware of a backlash. Remember laetrile? A somewhat toxic substance made from apricot pits that was supposed to cure cancer? When scientists reported the substance showed no efficacy whatever in the treatment of cancer, it was banned for sale in the US. Were the patients who had been treated with this worthless material angry with the charlatans who had profited from their continued suffering? No. Their anger was directed at the scientists who had exposed the fraud. They lobbied successfully for legislation that required the taxpayers to pay for new, more extensive trials. When laetrile failed these trials as well, they never wavered. They went to clinics across the border where they could still obtain the substance and continued to insist the treatment was working, until, one by one, they fell forever silent.

At least cold fusion is not fatal.

AAPT Concluding Remarks

Jack M. Wilson

American Association of Physics Teachers

My pleasant task this afternoon is to thank all of you for your active and successful participation in this conference of department chairs. This is the fifth such conference that has been held; and by capitalizing on the work of the previous conferences, it has been the most successful. The discussions show clearly that our departments have some common problems and issues and that we can all share perspectives and solutions. Equally important, there are some national issues facing physics and we have made some progress in understanding those issues and in planning some strategies and solutions.

In adopting a set of resolutions, we have spoken as a group on some of these topics. Our plan is to distribute these resolutions to physics departments around the country so that they have the benefit of our own perspectives, and that we might induce others to accept our views. In a similar manner, we have acted in concert to draft a letter to Allan Bromley, the new Science Advisor to President Bush. That letter, sharing the concensus of all the participants of this conference, will be sent to Bromley and will assure that our own views on the needs and prospects for physics education are brought to the highest level of policymakers in the nation.

Although we would not want to prejudge Bromley's response to our letter, it is most encouraging that the new Science Advisor is an eminent physicist respected for his own research and accomplishments and his commitment to science education.

Again, thank you for joining us. We have addressed some very important issues, and I believe we have made some progress toward their solution.

Four Summary Resolutions

The following are resolutions resulting from the Topical Conference on Issues in Graduate Physics Education and Research, held May 22–23, 1989, at the Key Bridge Marriott Hotel:

I. The Presidential Young Investigator (PYI) Awards were established originally to provide scientists with external research support during the critical early stages of their careers. Recently the guidelines for the PYI Program have been changed so that established scientists moving from industry or national laboratories to academics are also eligible for these awards. We support the original intent of the PYI awards and strongly support a return to the original guidelines.

II. We urge physics departments to review curricula for Ph.D. students and, in particular, to review core courses to reflect modern viewpoints made possible by recent developments in areas such as nonlinear phenomena and computational methods.

III. In light of the length of time required to obtain the Ph.D. degree in physics, we recommend that the AIP, in cooperation with APS, AAPT, and the department chairs, undertake a study of the term of the Ph.D. program.

IV. Women and minorities are seriously underrepresented in the physics profession. Failure to address this fact would not only perpetuate an existing inequity but also would contribute to the serious shortages of scientific personnel in the coming decades.

We recommend that graduate physics departments increase their efforts to address the problems of attracting and retaining these underrepresented groups. Furthermore, we recommend that the AAPT, APS, and AIP take leadership roles in helping physics departments address this issue.

Topical Conference on Issues in Graduate Physics Education and Research

May 22–23, 1989

Sponsored by:
American Assn. of Physics Teachers
5112 Berwyn Road
College Park, MD 20740-4100
(301)345-4200

with the cooperation of the
American Physical Society
Education Committee

Steering Committee

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Robert J. Swenson
Montana State University

Brian Schwartz
American Physical Society

Jack M. Wilson
Amer. Assn. of Physics Teachers

July 31, 1989

Dr. Allan Bromley, Director Designee
Office of Science & Technology Policy
New Executive Office Building
725 Seventeenth Street, NW
Washington, DC 20503

Dear Dr. Bromley:

The undersigned chairpersons and representatives of a significant fraction of the nation's Ph.D.-granting physics departments were participants in a Topical Conference on The Future of U.S. Doctoral Programs in Physics, May 22–23, 1989, sponsored by the American Physical Society and the American Association of Physics Teachers. From the materials discussed at this meeting, we are concerned that the United States academic physics community faces serious difficulties in ensuring an adequate supply of doctoral physicists to satisfy national needs. We are writing to express our deep concern over the ability of the federal agencies to address adequately this important national problem.

As we enter the 1990s, we fear that there will be a growing shortage of physicists in our nation's universities. The average age of physics faculty members is growing rapidly. In addition, universities are increasingly unable to attract talented new faculty. The availability and level of research funding for individual investigators has declined to such a degree that young physicists are choosing not to embark upon university career paths. In alarming numbers established, productive investigators are losing research support.

In view of the complexity of these very serious problems a detailed analysis is inappropriate here. We want to bring our concerns to your attention and request that you meet with a selected group of us. We look forward to your attention to these very important matters. Please respond to Dr. Homer Neal, chair of the steering committee.

Sincerely,

Physics Department Chairs

cc: Erich Bloch, Director, National Science Foundation
James D. Watkins, Secretary, Department of Energy
Richard Cheney, Secretary, Department of Defense

THE WHITE HOUSE
WASHINGTON

August 4, 1989

Dear Homer:

I am responding to the letter of July 31st that was signed by so many of the nation's physics department chairmen.

The concerns that they outline are ones that I fully share and efforts to do something about them will occupy a significant fraction of my time over the next few years.

I have become convinced that mathematicians, scientists and engineers, as distinct from other professions, tend to make their career decisions at a much earlier stage in their programs and that if we have not attracted people into these fields by their junior year in high school, we have, in most cases, lost them entirely. For that reason, in addition to maintaining current efforts to improve the situation at the college and graduate school levels, I hope to focus major attention on the teaching of mathematics and science at pre-college levels. One of the first tasks that I plan to give to the new President's Council of Science and Technology Advisers is a detailed study of the Federal role in pre-college education.

Later this fall, the President is committed to hosting an Education Summit here at the White House which will involve all 50 governors, and I again hope to have reasonably heavy involvement in that activity. As you know, a number of states, including Ohio, North Carolina, and Tennessee, to name only three, have made rather substantial progress in recent years and one of the functions that I believe my office can play is that of fostering and catalyzing the spread of such state initiatives.

I have been fortunate in being able to bring Mary Kruter, who has been primarily responsible for bringing the mathematics program at the Jefferson Magnet High School here in the Capital district to its present high state of excellence and visibility, onto my staff part-time. She will be very much involved in our efforts to do something constructive about improving the quality and quantity of high school mathematics exposure. I intend to use this as a model which can subsequently be extended to the sciences if it is as successful as we hope it will be.

I can assure you that the President really means it when he says that he wishes to be known as the Education President and I know that I can count on his support. Although I have not yet had an opportunity to do so, I plan to visit with the Secretary of Education and try to arrange as much as cooperation as possible with his activities.

With respect to the very important question of infrastructure, Packard and I in 1986 estimated that $10 billion dollars would be needed over the next 10 years to bring the research universities up to a reasonable level from which they might hope thereafter to be self-sustaining. Much the same numbers have emerged from the study headed by then Representative, Don Fuqua, and from a number of examinations of this problem. I believe that there is a very real sentiment in the Congress to try to provide the kind of support that all of these studies have recommended, namely, $5 billion in Federal funding, to be matched by $5 billion in non-Federal funding over a period of some 10 years. Unfortunately, the '90 and '91 budgets are going to be extraordinarily tight and it is questionable just how far we can go in starting this program. Erich Bloch, at NSF, has decided as a matter of tactics to eliminate the infrastructure line from his FY '90 budget altogether, and is seeking to work a deal to include it in substantial fashion in FY 1991. There is general recognition that the problem is real and that it must be addressed by the Federal Government.

As Packard and I suggested, and as I believe most people now agree, once the backlog of deferred maintenance and other costs is taken care of the hope is that the universities can become self-sustaining if reasonable amortization schedules are used for both buildings and equipment in agency indirect cost scheduling.

I concur in your conclusion that there will be a very serious shortage of physics faculty in the nation's universities in the 1990s as the age pulse appointed in the immediate post-Sputnik era retires. I also anticipate very much increased competition among the universities for the relatively small number of high quality candidates.

I understand your concern about the funding situation, but I must emphasize the unfortunate demographic fact that with some 87% of all the physicists who have ever lived active at the present time, and with their number increasing at a significant greater rate than are the available funds, even on optimistic projections, we face an inevitable situation where if new young physicists are to be funded, some established physicists can no longer anticipate receiving the level of funding that they have come to expect and enjoy. This is a problem that NSF and NIH are both facing and it is unquestionably a most difficult one.

I would, of course, be happy to meet with a group of physics department chairmen and would be most interested in hearing the results of their analysis of the present situation, and their recommendations for specific Federal action. I cannot, of course, guarantee such action, but would look forward to this meeting as an important input to the activities of this office.

Might I suggest that you contact Ms. Marian Nida at (202) 456-7116 so that she can arrange an appropriate time for us to get together. I would appreciate it if you would be good enough to let me have a listing of those whom you would wish to have accompany you at this meeting.

With best personal regards,

Sincerely yours,

Allan

D. Allan Bromley
Assistant to the President
for
Science and Technology

Dr. Homer A. Neal
Department of Physics
The University of Michigan
Ann Arbor, Michigan 48109

APS Closing Remarks

James A. Krumhansl
1989 President, American Physical Society

September 1989: Since the Topical Conference on Issues in Graduate Physics Education and Research in May 1989, events have already overtaken the potential problems discussed at the conference. The situation for the funding of small science grants to individuals has become even worse than portrayed at the conference as a result of congressional actions and policy decisions at agencies. Accordingly, on behalf of the American Physical Society, I have sent letters to the President, the Science Advisor, and the Fellows of our Society describing the situation. This material follows. I hope that you will find it informative.

Anyone involved in graduate education in physics realizes that grants to individuals are the backbone to our American system. Yet we face two serious problems. First, our legislators are not aware of this; indeed, they sincerely believe that they are doing well by science in funding a few, highly visible programs. Second, senior administrators at science-supporting agencies have chosen to use their limited resources for special programs, while the infrastructure is being continually constricted.

At the same time, it is apparent that the President, Congress, and your state Governor rarely hear from the graduate educator. They must understand that adequate and continuing support of the individual investigator is essential to the competitive, educated work force of the future. In this arena, only one thing really counts – votes. Unless each and every one of us pauses in our work and takes the time to write to his representatives, the situation can only deteriorate further. However hard they work, leaders of the physics community have only slight political weight. If the problems are yours, so also is the way toward the solutions. Speak out!

The American Physical Society

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David Lazarus
University of Illinois

Office of Public Affairs
Robert Park
University of Maryland

September, 1989

To the Fellows of the American Physical Society:

GREETINGS.

The current crisis in federal funding of physics has prompted me to take the unusual step of sending a special message to APS Fellows. Funding has become so uncertain during the past few years that many of our physics institutions--basic research, facilities, education--are in serious danger of crumbling, even in the near future. The most sobering aspect of this erosion is that it has progressed almost unnoticed in congressional and executive actions. Indeed, many of our legislators believe that, by funding a few major high-visibility projects, they are doing quite well by science.

Under these circumstances, it is important to keep the leaders of the physics community posted on recent developments (please take a moment to read the items in the enclosed packet). Perhaps a prime concern is the budget of the National Science Foundation in FY 1990, and the upcoming budget request for FY 1991. NSF plays a major role across science in providing base support for research and science education. However, these concerns apply to many other agencies as well. The problems of the individual investigator are particularly serious.

The officers of APS have taken a number of steps to express our concerns to the Administration and, particularly, to the new Science Advisor, Allan Bromley. We are, however, but a few voices. The President, Congress and the Governor of your state need to hear directly from you, their constituents. Do not underestimate the impact of your participation in this process.

Please think about the ramifications of these developments on your institution, your field, the education and support of students, and your community and discuss these matters with your representatives, local and national. In voicing our concerns, we also must remain sensitive to the broader concerns of the Nation. This is not the time to plead only for particular programs or projects, but it is the time to defend the value of scientific research and education.

As a Fellow of the APS and a leader in the physics community, I hope that you will share this message with your colleagues. We must make ourselves and our views known to our elected representatives. The time is now. The FY 1991 budget clock is ticking relentlessly.

Sincerely,

J. A. Krumhansl
President

attachments

The American Physical Society

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University of Maryland

August 5, 1989

The President
The White House
1600 Pennsylvania Avenue, N. W.
Washington, DC 20500

Dear Mr. President:

I am writing on behalf of the governing council of the American Physical Society to express our profound concern over the current funding crisis in the National Science Foundation.

We share with you the sense of promise in the future welfare of our country that science and technology can provide. Your commitment to the realization of that promise is demonstrated by your support for major new projects, such as the Superconducting Supercollider, which are visible symbols of America's commitment to remain at the forefront of world science.

You have also sought adequate funding for the multitude of less conspicuous research projects, ranging from materials science to quantum optics, that actually drive the engine of progress. It is from these projects that such important new developments as high temperature superconductivity have emerged. This has led to a spectacular world-wide increase in activity in these fields. Unfortunately, the budget of the National Science Foundation, which bears the major responsibility for the health of these vital programs in the United States, has not kept pace with this growth.

To restore balance to America's research effort, your budget request to Congress endorsed the goal of doubling the NSF budget in five years. Your appointment of our distinguished colleague, Allan Bromley, as your Assistant for Science and Technology serves to reinforce that commitment. It was Allan Bromley, after all, together with David Packard, who co-authored the 1986 White House report, "A Renewed Partnership," in which the goal of doubling the NSF budget was first articulated.

Unfortunately, in the years since the Packard-Bromley report was issued, a Congress beset with growing deficits has consistently failed to make the annual investments in NSF called for by the Administration. It now appears that FY 1990 will be no different. Indeed, Congress seems to be moving toward an NSF increase less than half that called for in your request.

The consequences of this continued neglect are palpable. Renowned researchers, even Nobel laureates, find themselves devoting an ever greater fraction of their energies to the quest for research support, rather than to the pursuit of knowledge. Promising young faculty discover that they are excluded by a system that cannot support new starts in research. Witnessing this, the brightest youth of our nation, who would once have eagerly sought the challenge of basic science, increasingly turn away from academic careers. My concern is shared by the entire physics community, as the enclosed statement signed by a group of the nation's leading physicists attests.

And yet, the investment that would be required to restore the United States to its former position of clear preeminence in science and technology is small when compared to the cost of the major technological programs to which they contribute. The trained scientists and engineers, as well as the base of technical information, that are required for any major technological undertaking are the products of National Science Foundation support. We must, therefore, learn to relate the level of support for science to the ever increasing technological needs of the nation. The research budget of the NSF in FY 1989 is about $1.6 billion to cover all fields of science. That is only about $26 for each American family, a tiny fraction of the cost of the technology programs that benefit from the work of the NSF. What an opportunity for an enormous return from a modest increase in investment in the future!

We urgently appeal to you to give your personal attention to the effort to restore funds cut from the National Science Foundation in the FY 90 budget and to give NSF the highest priority in the coming weeks as you develop your budget request for FY 91. We appreciate your leadership in this vital effort.

Respectfully yours,

James A. Krumhansl
President

cc: Governor John H. Sununu
Mr. Richard G. Darmon
Dr. D. Allan Bromley
Mr. Erich Bloch

The following are recent excerpts from WHAT'S NEW, the weekly electronic information bulletin from the APS Public Affairs Office in Washington.

(15 Sept. 89) NSF, THE AGENCY WITH NO ENEMIES, TAKES IT ON THE CHIN AGAIN. This week, the Senate Appropriations Committee accepted its subcommittee recommendation to give NSF $30M less for research than the House voted in July (WN 28 Jul 89)--and the House figure was $88M below the President's request--and thatrequest was not enough to keep pace with growth in critical areasof science. A $20M Facilities Modernization Program would be funded with money skimmed from research. That won't buy many facilities, but it would probably eliminate any new research starts. It is not clear what will happen in conference with the House if the full Senate backs the Subcommittee on the facilities issue. The House refused to fund the facilities program, which was authorized last year, precisely out of fear that the money would wind up coming out of research. Moreover, the program is burdened with restrictions that seem designed to ensure that universities that do research don't get facilities. The subcommittee markup ended with the members congratulating each other on the fine job they had done.

(15 Sept. 89) THE FY 90 APPROPRIATION FOR MAGNETIC CONFINEMENT FUSION ended up at $331M, which is $18M below the administration request. The conference report expresses concern about the slow progress, but rather than attempting to micromanage, Congress took the unusual step of leaving it to DOE to decide how to distribute the money among the elements of the program. Congress apparently ignored a request by Robert Hunter to transfer $50M to inertial fusion.

(8 Sept. 89) THE HOUSE AND SENATE REACHED AGREEMENT ON THE SUPERCOLLIDER yesterday. A Conference Committee accepted the Senate figure of $225M, which is $25M more than the House had voted, provided the extra $25M be used for the first sector tunnel contract. Foreign participation is a problem: "The conferees agree that foreign participation in the SSC may negatively impact the development of high technology in this country and foster development outside the US. On the other hand, foreign contributions may make a significant reduction in the cost of the SSC." Wrong both times! Their "solution" is to require foreign-participation agreements to be approved by Congress. The Committee was also concerned about what it called, "credibility concerns associated with the SSC cost estimate." They said the R&D accomplished this year should enable DOE to make a more precise cost estimate.

(1 Sept. 89) THE BROOKHAVEN ALTERNATING GRADIENT SYNCHROTRON USERS GROUP has mounted a lobbying effort to restore the $10M the Senate cut from the FY 90 AGS budget (WN 28 Jul 89). "The proposed cut means the end of particle physics at the AGS," according to a statement circulated by the Chairman of the AGS Users Group. "While it has been assumed that some existing facilities will be closed when the SSC becomes operational," the statement says, "it was never envisioned by any of the advisory panels that a major assault would begin on existing facilities 10 years in advance of the SSC." Citing rumors of a 50% cut for SLAC and Fermilab in FY 91, the statement says closing these facilities in a few years could "kill the future of the field." The only chance to restore the AGS funds will be when a Conference Committee meets after Labor Day to resolve differences between the House and Senate versions. Although the House did not target a particular program, it did take a big cut from General Science and Research (WN 30 Jun 89).

(4 Aug. 89) THE NATIONAL SCIENCE FOUNDATION FACES DISASTER AGAIN IN FY 90. It has been nearly four years since the Packard-Bromley report, "A Renewed Partnership," articulated the goal of doubling the NSF budget in a few years. Both the Reagan and Bush Administrations endorsed a five-year goal, but a Congress beset with growing deficits has consistently declined to make the annual investment of 14% above inflation. It now appears that FY 90 will be no different. The appropriation bill recently passed by the House increases NSF only 6%--a twelve year doubling rate

assuming zero inflation. Moreover, the House voted to remove a prohibition against using NSF funds for a program of University Facilities Modernization. This is ominous. The facilities program had been authorized, but not funded, and the prohibition was needed to protect the already anemic NSF budget from pork-barrel raiders.

Can the Senate be expected to help? The prospects are bleak. For one thing, the allocation for the Appropriations Subcommittee responsible for NSF is about $500M short of its expectations. They had counted on advancing the pay dates of some agencies to make them fall in FY 89, thus generating a paper savings in FY 90. Alas, the leadership disallowed the scheme. However, Congress departs today for the summer break, and the Senate will not act on the NSF appropriation until it reconvenes after Labor Day.

This offers a brief reprieve, during which the science and technology community can endeavor to make the Senate aware of the importance of the NSF to our national goals. Most senators are under the impression that the NSF has fared comparatively well in these Gramm-Rudman years. They will point out that even though the NSF budget is not on track for doubling in five years, annual increases have exceeded inflation. In this period, however, the Foundation has assumed responsibility for new programs in science education, and established a number of centers in engineering and science. Moreover, there has been a phenomenal world-wide growth in areas of science and engineering linked to new technologies. The continued inability of the NSF to keep pace with this growth jeopardizes the leadership of the US in these critical areas.

The consequences are palpable. Renowned scientists devote an ever greater fraction of their energies to a search for research support, rather than to the pursuit of knowledge. Promising young faculty find themselves excluded by a system that cannot support new starts in research. Witnessing this, the brightest youth of our nation increasingly turn away from academic careers. The training of the next generation of scientists is at risk.

This is not the time to plead for particular projects, but it is the time to defend the agency that represents the heart of science. Congress is in recess, but your senators can be reached through their home state offices. If you need information, call.

(28 Jul 89) NSF IS DOING POORLY IN THE FY 90 APPROPRIATIONS PROCESS. The full House approved the $2B figure for NSF recommended by the Appropriations Committee (WN 14 Jul 89)--an increase of only 6%. The Senate will not act on its version of the bill until Sept.

(28 Jul 89) MEANWHILE, THE SSC IS FLYING HIGH. THE SENATE APPROVED $225M for the project, $25M more than the House (WN 30 Jun 89). In the same bill, the Senate added $30M to an Administration request for a study of global warming. Initially the money was taken from the Alternating Gradient Synchrotron at Brookhaven, but Sen. D'Amato (R-NY) succeeded in restoring $20M of the diverted funds.

(14 Jul 89) NSF AND NASA WERE CUT BY THE HOUSE APPROPRIATIONS SUBCOMMITTEE this week (WN 30 Jun 89). The total FY 90 figure for NSF is about $2B, which is $150M below the request and only about 6% over FY 89--that is a doubling rate of nearer 12 years than 5. The figure for research was about 8.3% above last year, while education was increased a whopping 23%--which is $20M above the request. The money came from the Antarctic Program, which was funded at about half the level of the request, but DOD is expected to pick up the slack. Although NASA got about $1B less than it requested, the space station survived. There is still a long way to go in the FY 90 appropriations process, but it's not too early to panic.

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Date Filmed

March 29, 1991